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Relation of Silurian Reefs to Ordovician Structure in the Patoka Oil Area

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ABSTRACT

Oil has been produced from Mississippian rocks in the Patoka area, Marion County, since 1937, but only in the last three years has it been produced from the Ordovician rocks, namely the Kimmswick ("Trenton") Limestone. Because there appeared to be good possibilities of extending Kimmswick production, a study of the subsurface geology was undertaken. The results of this study indicate that Kimmswick production might be extended northeastward and southwestward from the Fairman pool.

The Silurian reef structures at Patoka and Patoka East were found to have been developed on the northeast noses of pre-existing Ordovician anticlines which apparently were a controlling factor in the development of the reefs.

The presence of the Ordovician structures are reflected in isopach and structure maps of the Pennsylvanian and Mississippian rocks.

Some structural features are noted that may indicate the presence of other reef-like structures in the area.

INTRODUCTION

This study of the relationships between Silurian reefs and known "Trenton" structure in south-central Illinois was prompted by recent discovery of "Trenton" oil production and was undertaken with the hope that it might disclose other possible accumulations of oil.

The Patoka oil area, as defined in this report, consists of 132 square miles in Clinton, Fayette, and Marion counties (fig. 1). Oil is produced from six pools. The area has six pay zones, four of which produce in the Patoka pool from rocks that range in age from Ordovician to upper Mississippian. The area has produced oil since the discovery of the Patoka pool in 1937, but the importance of Kimmswick production is slight as compared to that from Chester and, to a minor degree, Devonian in the Patoka pool.

Kimmswick production figures from Patoka and Fairman pools indicate that the ratio of oil recovered per well has been low or in the marginal range to January 1958.

From the Patoka pool, nine wells, in production from one to two years, have yielded approximately 122,000 barrels of oil, and eight other wells, producing less than three months, yielded approximately 51,000 barrels of oil.

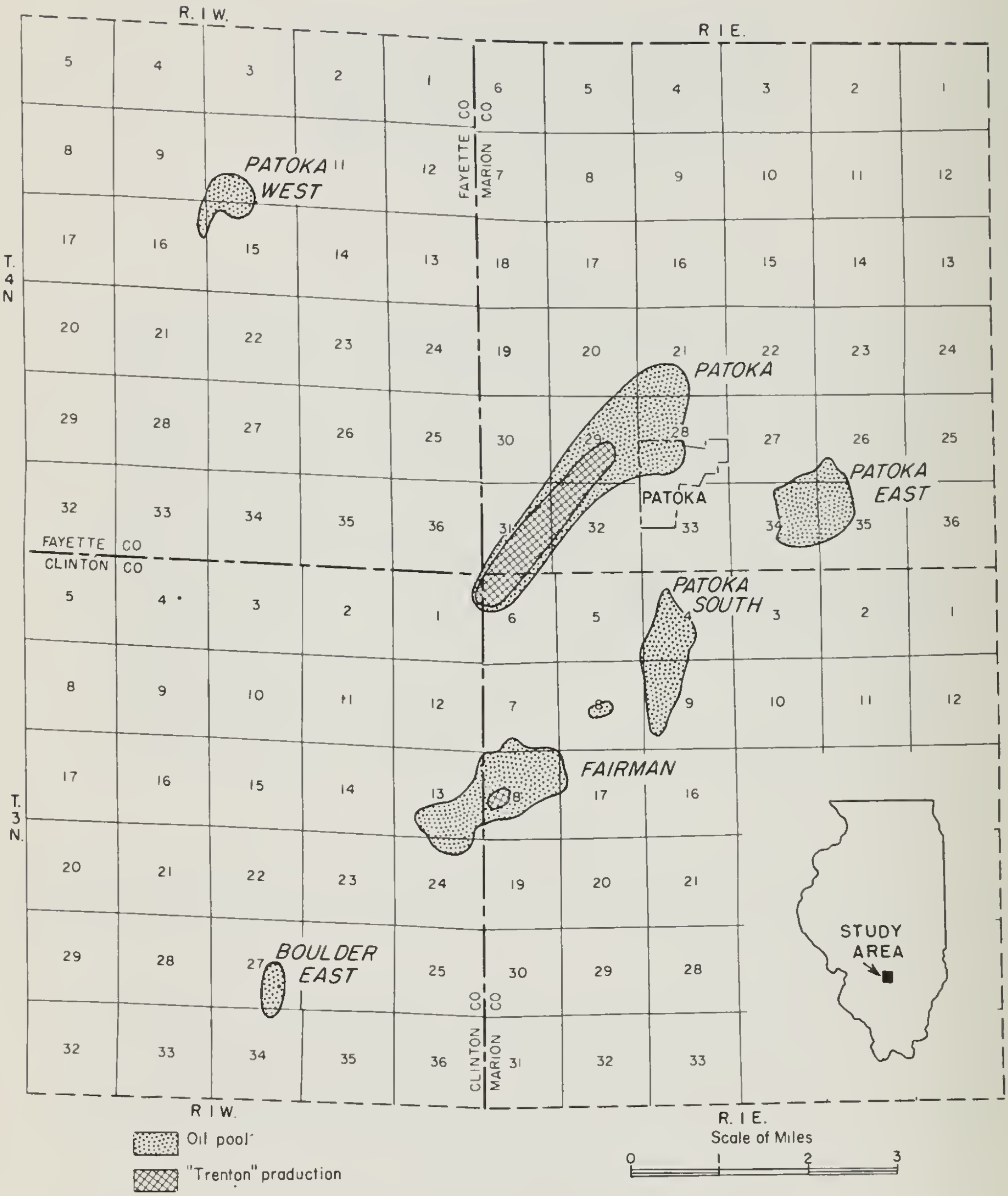


Fig. 1. - Index map of Patoka area showing oil pools.

In the Fairman pool, four wells have produced approximately 12,500 barrels in less than eight months. These figures are based on the "Pipeline Production Report," December 1957, and personal communications from oil producers.

This investigation is based essentially on an isopach and structural map study. Data were obtained from micrologs and electric and induction logs. Supplementary information was obtained from driller's logs, drilling reports, and, to a minor extent, sample studies, all of which are on open file at the Illinois State Geological Survey in Urbana.

The datum surfaces used for this investigation were chosen because 1) they are easily recognized on geophysical logs and on driller's logs, 2) they are continuous in extent throughout the area, 3) the key beds show little lateral variance, 4) they are a sufficient stratigraphic distance from a major erosional surface to show possible structural anomalies, as reflected by differential compaction, and 5) they afforded maximum control for each geologic system or series.

Where convenient, the strata chosen were those used by Brownfield (1954) in the Centralia area which adjoins and in part overlaps the Patoka oil area.

Acknowledgments

Thanks are due to Wayne F. Meents of the Illinois State Geological Survey who introduced the problem and who furnished much information for the study. Other Survey staff members who contributed suggestions and advice are David H. Swann, who advised me on stratigraphic interpretations, procedures, and techniques, and Lester L. Whiting, A. H. Bell, and Elwood Atherton, who described the contact between the Warsaw and Salem Formations. John Van Fossen of the Kewanee Oil Company supplied information, porosity data, and personal opinion. Ronald A. Younker and Jerry L. Williams of the Survey gave technical assistance.

STRATIGRAPHY

A summary of the stratigraphy of the Patoka area is presented in the columnar section (fig. 2). For purposes of this report, the Pennsylvanian rocks are subdivided at the base of the Shoal Creek Limestone and at the base of No. 2 Coal. The youngest sequence, that above the Shoal Creek Limestone, was not used in this study.

The Shoal Creek Limestone is 8 to 12 feet thick, light colored, and well consolidated. It is characterized on electric logs by its abnormally high self-potential values. The base of the limestone has been used as a marker bed for figure 3, which indicates that Ordovician deformational and younger differential compaction structures are reflected at shallow depths.

The sequence of rocks between the Shoal Creek and No. 2 Coal is composed of silty shales with many thin coal beds, thin limestones, and locally thin, medium-grained sandstones.

No. 2 Coal is recognized on electric logs in this area by its low resistivity values on the 16-inch normal curve and more easily on the 64-inch normal curve. There are three similar pairs of curves in a 50-foot interval, the top one representing No. 2 Coal approximately 70 feet below No. 4 Coal.

The oldest sequence of Pennsylvanian rocks below No. 2 Coal are characterized by sandy shales and thick sandstones. There are few limestones or coals.

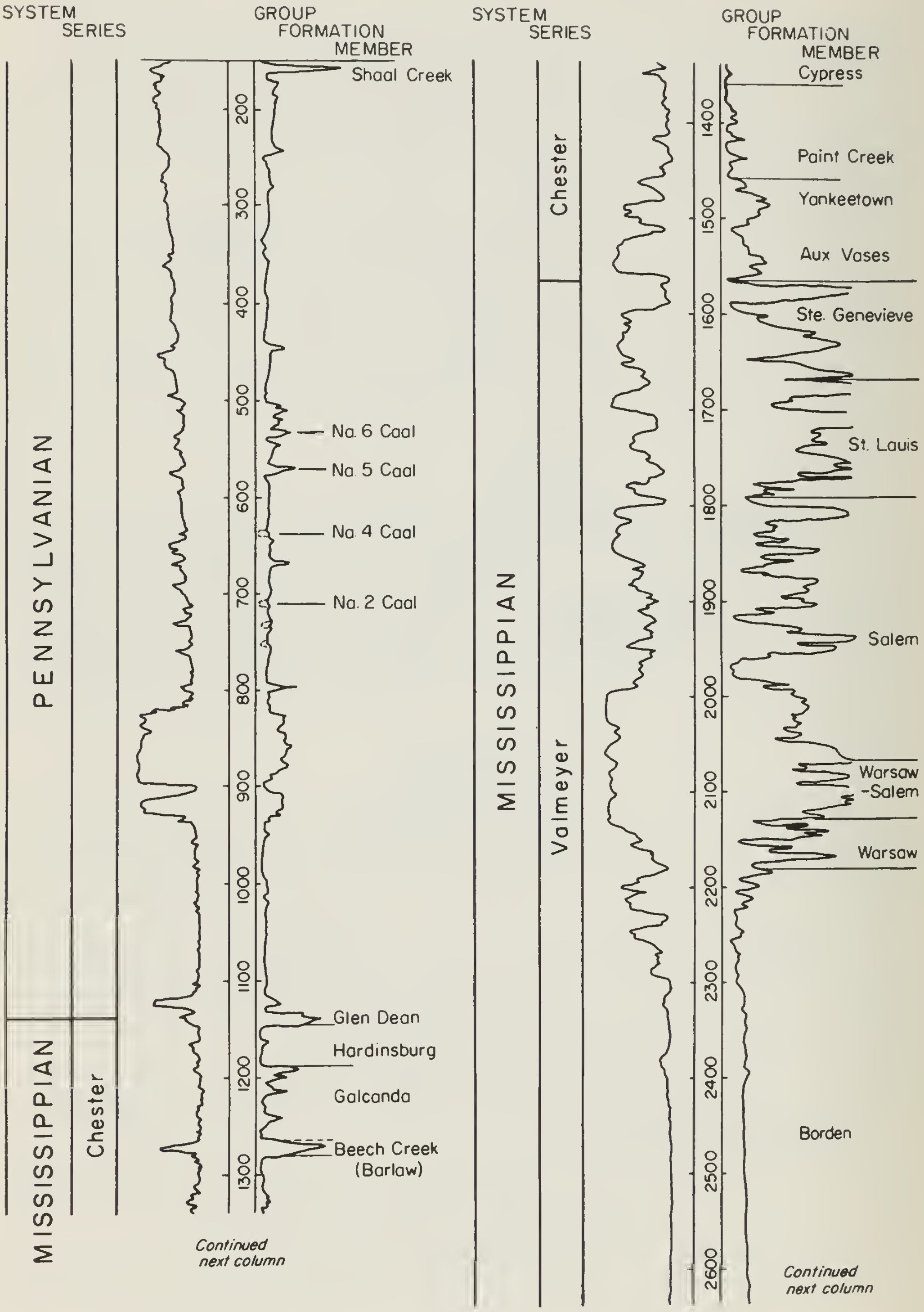


Fig. 2. - Stratigraphic column.

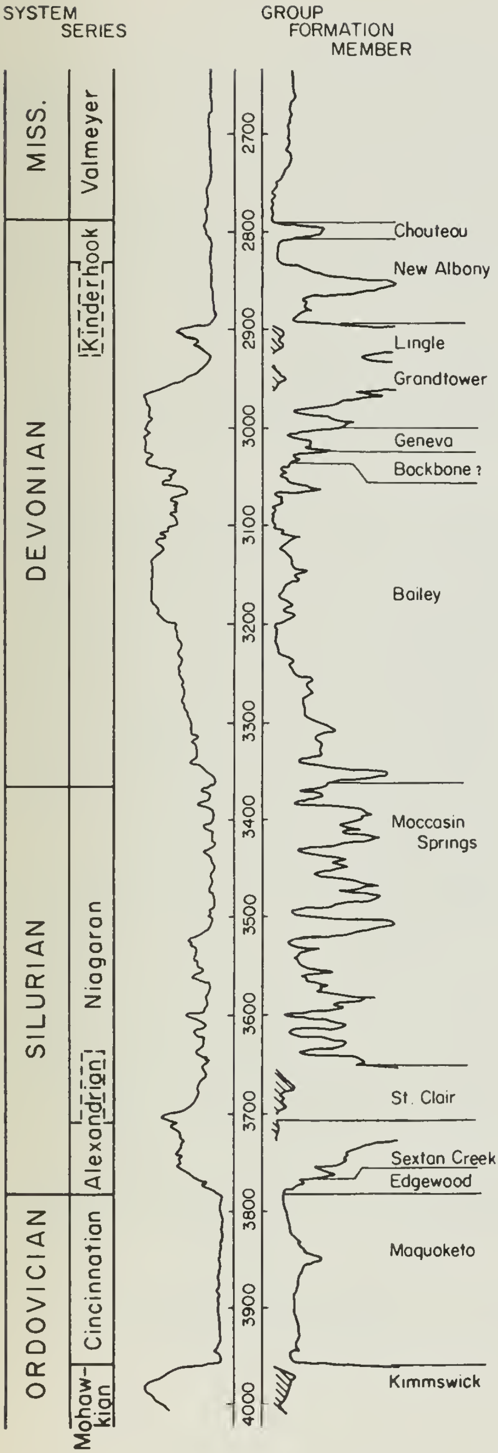


Fig. 2. - Stratigraphic column, continued.

A thick sandstone is present throughout most of the area, lying 100 to 150 feet below No. 2 Coal. This sandstone generally is underlain by a sandy shale at least 150 feet thick.

The youngest Mississippian strata are a succession of alternating limestones, sandstones, and shales of the Chester Series. The sandstone units vary laterally in thickness. The Glen Dean Limestone is the highest Chester stratum present in the area, as overlying Chester formations were removed from parts of the area by pre-Pennsylvanian erosion (fig. 2).

The interval between No. 2 Coal and the base of the Glen Dean Limestone is important because it represents a time of major tectonic activity in the Illinois Basin, a time when the major development of the DuQuoin monocline took place. Both No. 2 Coal and Glen Dean Limestone can be assumed to have been deposited essentially horizontally and evenly over a great area. Both are far enough stratigraphically from the pre-Pennsylvanian erosional surface to have been little affected by pre-Pennsylvanian topography.

The Glen Dean Limestone is light brownish gray, dense, and slightly sandy. It is easily recognized on electric logs that go below the sandstone of the Tar Springs Formation or the basal sandstone of the Pennsylvanian. The base of the Glen Dean affords the best control of all the datum surfaces used in this area because it has been penetrated at many places and is easily recognized on geophysical logs, driller's logs, and in sample sets. Its base is used as a marker surface in figures 4 and 5.

The top member of the Ste. Genevieve Limestone, the Levias Limestone, is recognized on electric logs as the top limestone member of the carbonate section of the Valmeyer

Series below the lower Chester sequence of sandstones and shales. In the Patoka area, the base of the Aux Vases Formation, the oldest Chester formation, is represented by a thin shale member of variable thickness. The Levias is approximately 20 feet thick and in many places is underlain by a sandstone member. The low self-potential and high resistivity of the Levias is therefore conspicuous in comparison to the overlying and underlying high self-potentials of the sandstones.

The Valmeyer Series comprises approximately 1200 feet of sediments divided about equally between carbonates and silty shales. The Ste. Genevieve Limestone, the top formation of the carbonate section, is mainly oolitic, slightly sandy and cherty, brownish gray to light gray, and massive. The rest of the carbonate section is partly cherty.

The older half of the Valmeyer Series is represented by the Borden Group which is composed mostly of silty shale and is approximately 600 feet thick.

The Kinderhook Series is represented by the Chouteau Limestone and the upper portion of the New Albany Shale. The Mississippian-Devonian boundary falls within the New Albany Shale.

The interval between the top of the Ste. Genevieve Limestone (Mississippian) and the top of the Lingle Limestone (Devonian) is significant in a structural interpretation of the area. During the time represented by this interval, little significant structural deformation occurred in this area. Southeastward deepening of the basin is obvious. Figure 6 is an isopach map of the interval between the top of the Ste. Genevieve and the Lingle Limestone.

The Lingle Limestone just below the New Albany Shale is easily recognized on electric logs by its relatively high self-potential and high resistivity values.

The Devonian rocks on top of the Silurian serve to modify Silurian structures, but it is difficult to determine any specific marker closer to the top of the Silurian than the Lingle. The top of the Lingle, therefore, is the best available marker for a structure and isopach study of the Silurian rocks.

The upper part of the Devonian carbonate section is, for the most part, slightly sandy dolomite and limestone and is underlain by a cherty dolomite and cherty limestone sequence. The Silurian System is represented by argillaceous limestone, silty dolomite, and local, pure carbonate, reef and reef "wash" accumulations.

Although information is scarce, it appears that no significant structural movements took place in this area during the time represented by the interval between the Lingle and the Kimmswick ("Trenton"). Therefore, the anomalous thin rock intervals indicated in figure 8 reflect pre-existing, deformational structures; the anomalous thick rock intervals are thick due to the Silurian reefs and accumulations of reef "wash."

The top of the Kimmswick ("Trenton") Limestone of the Ordovician System is easily recognized on electric logs because the high resistivity of the limestone contrasts sharply with the low resistivity of the overlying Maquoketa (Cincinnatian) Shale.

The Maquoketa (Cincinnatian) Shale and the Kimmswick (Mokawkian) Limestone are the only part of the Ordovician System drilled in the Patoka area.

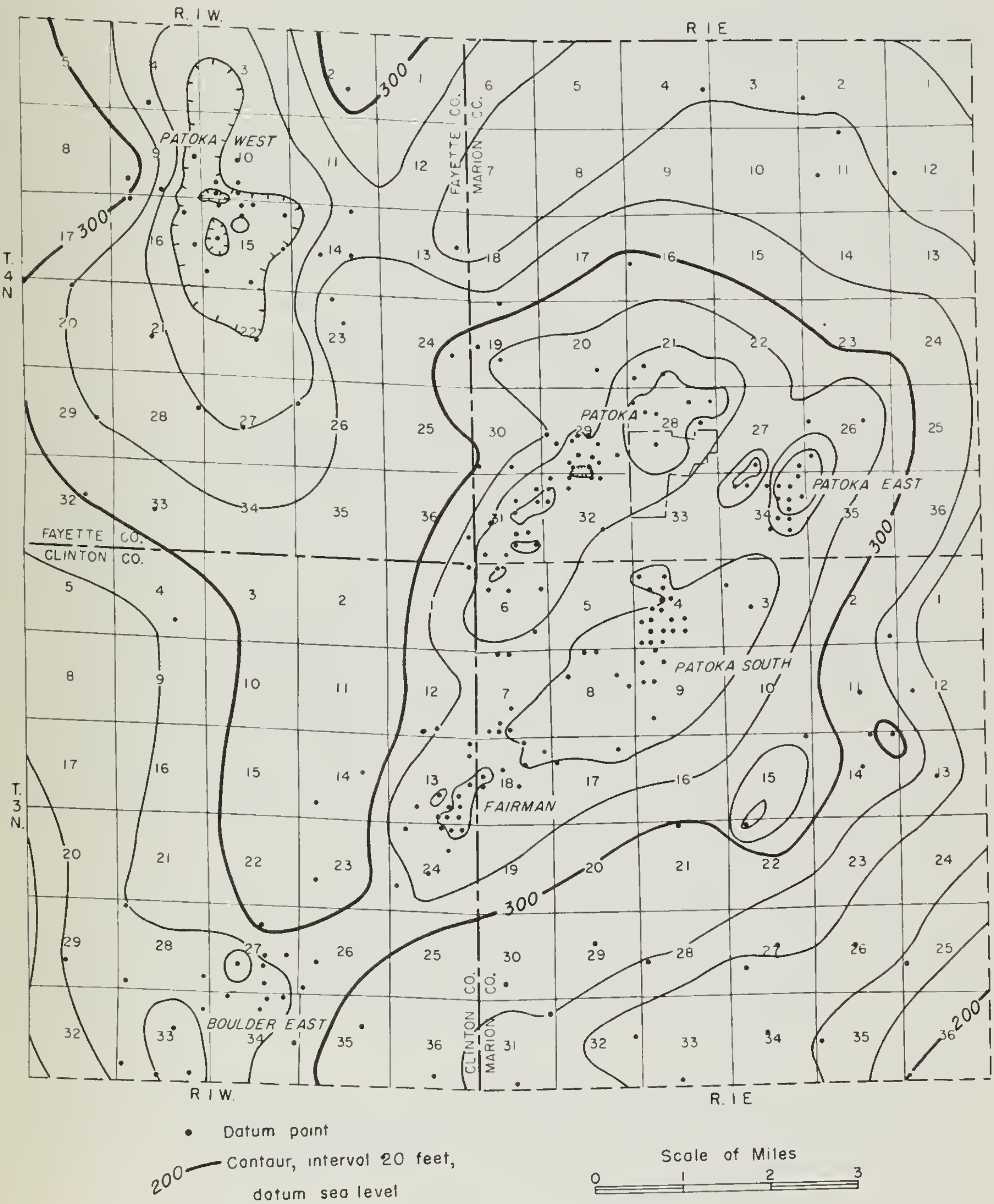


Fig. 3. - Structure map base of Shoal Creek Limestone (Pennsylvanian).

STRUCTURE

The structural complex extending from sec. 28, T. 4 N., R. 1 E. southwestward to sec. 1, T. 3 N., R. 1 W. is here referred to as the Patoka structural complex. It consists of two main components: 1) the deformational anticline southwest of the town of Patoka, which is referred to as the Patoka deformational anticline; and 2) the Patoka reef structure. The more extensive structural complex extending approximately from sec. 26, T. 4 N., R. 1 E. to at least sec. 34, T. 3 N., R. 1 W. is referred to as the Patoka East structural complex. This complex also consists of two main components: 1) the deformational anticline extending southwest from the Patoka East pool through the Patoka South, Fairman, and Boulder East pools, referred to as the Fairman deformational anticline; and 2) the Patoka East reef structure.

Structure at the Base of the Shoal Creek Limestone (Pennsylvanian)

Figure 3 shows a central high that includes the Patoka East structural complexes. The two structures are separated by a narrow shallow trough that is roughly parallel to the two structures. The highest points in the central portion of the map are closed highs at the northeast ends of the structures. These closed highs reflect underlying reef structures. The reef structures are more distinctly indicated than the anticlinal folds. However, the large closed highs associated with the reefs reflect deeper deformational structures.

In T. 4 N., R. 1 W., a structural low is apparent. The center of this low is located at the Patoka West oil pool. The closed low spot, centered in section 15, apparently is a phenomenon restricted to the Pennsylvanian strata. On a structure map of No. 2 Coal, the same low would be apparent but in modified form. In the Chester it is a nearly flat, structural terrace (fig. 5); in the Ste. Genevieve it appears as a narrow terrace, and it apparently disappears below the Valmeyer rocks (fig. 7). As this low, as such, apparently is restricted to the Pennsylvanian sediments, high compaction of those sediments is suggested as a possible explanation. The elongate low trough extending northeast of this low seems to be genetically related to it.

A small, high structure appears in secs. 15 and 22, T. 3 N., R. 1 E., the position of which is indicated at greater depths as a subdued, more extensive high (figs. 5, 7, and 9). Its sharpness, as shown at the base of the Shoal Creek, may be due to the presence of Pennsylvanian sands with low compaction values. This might have resulted in an oval high causing a "draping" effect of the Shoal Creek Limestone as the surrounding sediments were compacted to a greater degree.

The structural high at Boulder East (secs. 27, 28, 33, and 34, T. 3 N., R. 1 W.) may reflect an underlying reef structure or may reflect the intersection of cross folds. This structure is discussed in more detail below.

The regional dip, although not clearly shown in figure 3, is toward the east and south (Brownfield, 1954, p. 27, fig. 10; Siever, 1950).

Thickness of Lower Pennsylvanian-Upper Chester Strata

Figure 4 is an isopach map showing the thickness of the interval between No. 2 Coal (Pennsylvanian) and the base of the Glen Dean Limestone (Chester). The time interval represented by this thickness is structurally important in the Illinois Basin.

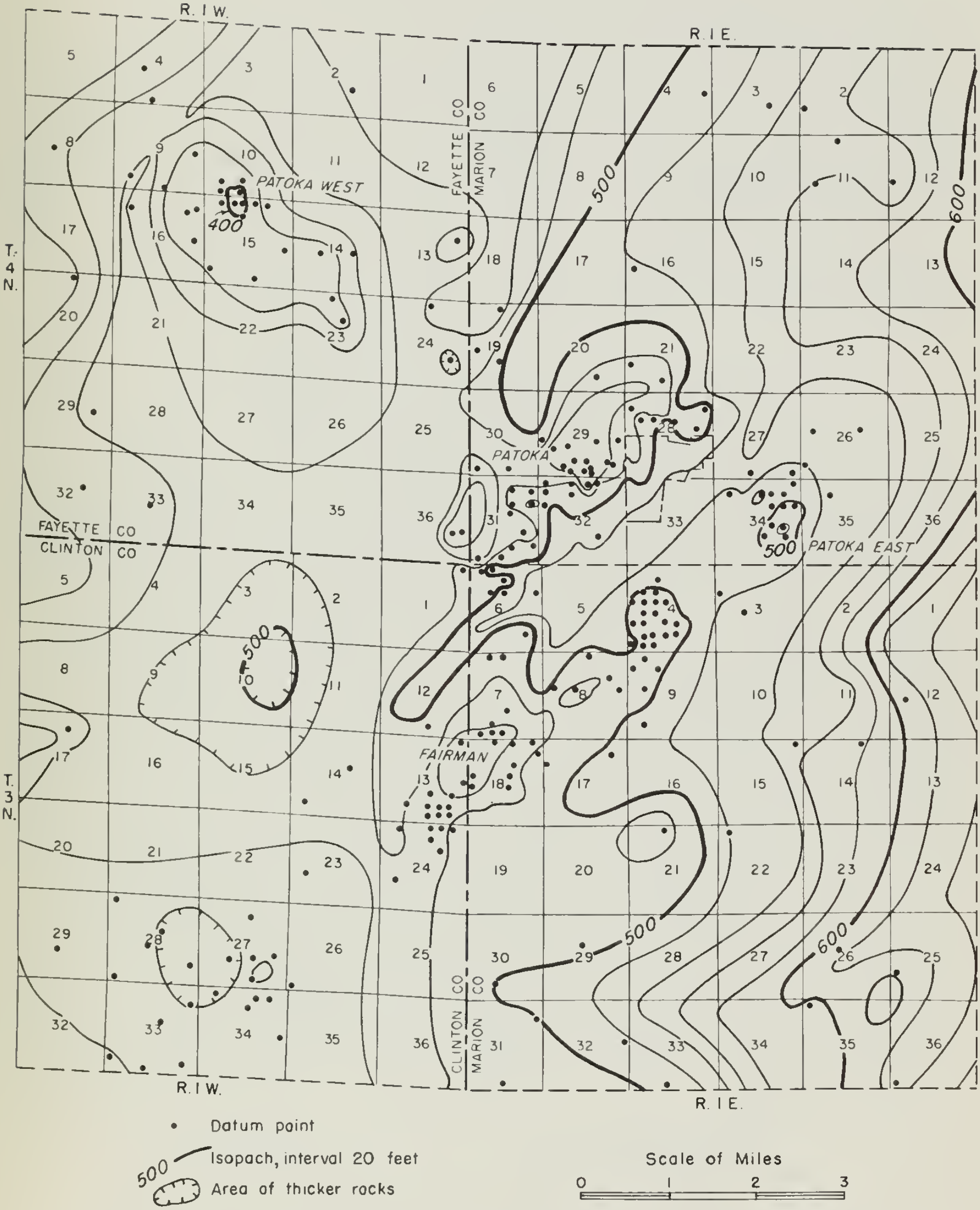


Fig. 4. - Isopach map showing thickness of the Lower Pennsylvanian, Upper Chester strata (No. 2 Coal to base of the Glen Dean).

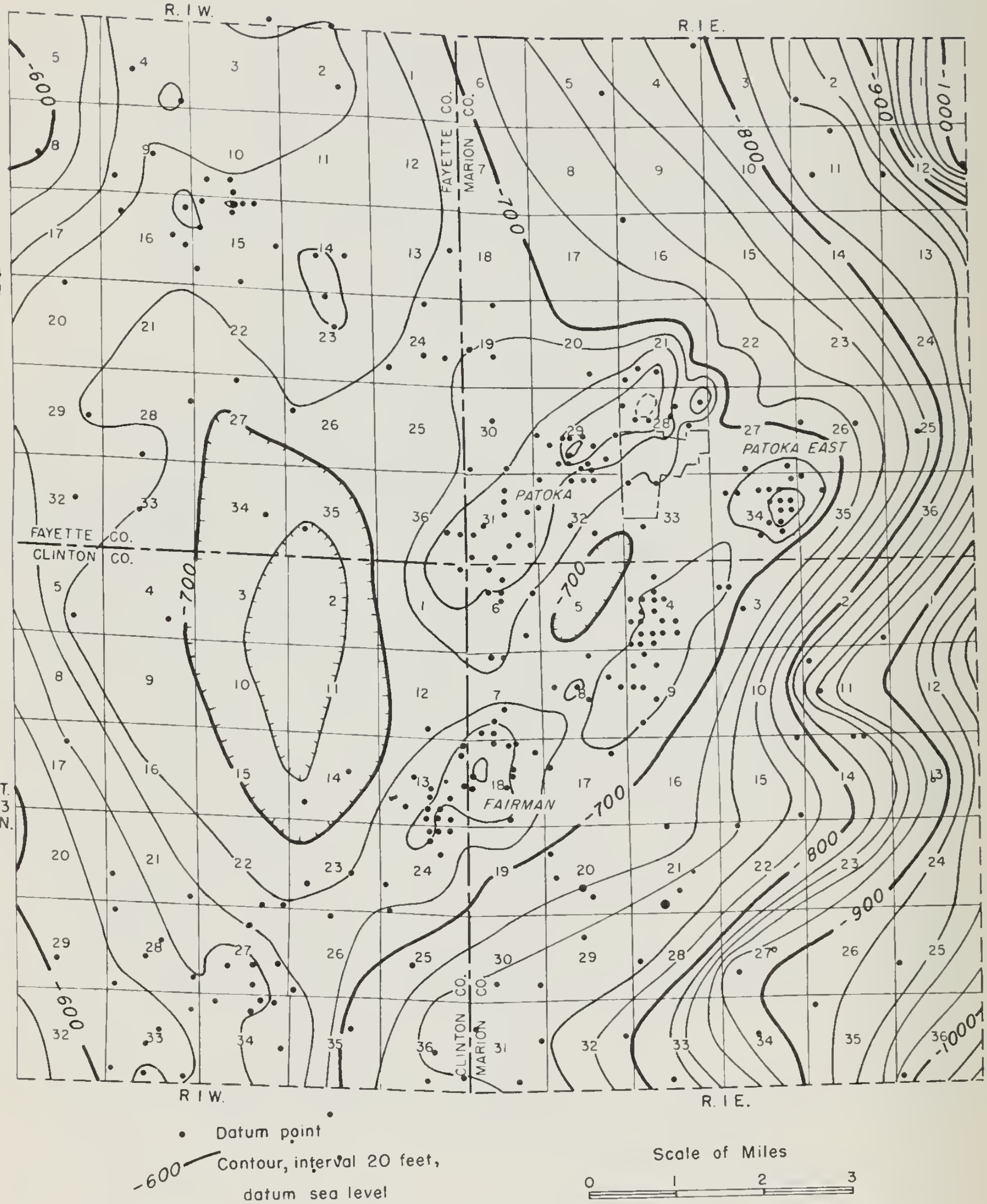


Fig. 5. - Structure map of base of the Glen Dean Limestone (Chester Series).

The Patoka and Patoka East structural complexes are delimited as open and closed thin areas. As discussed above, the features shown here should not have been affected by pre-Pennsylvanian erosional topography. It can be assumed, therefore, that the thin areas reflect deeper structures that were present during deposition of the upper Chester and lower Pennsylvanian rocks and caused differential sedimentation and compaction. The structural deep shown in figure 3, centered in T. 4 N., R. 1 W., is indicated on figure 4 as a closed thick area. The structurally flat area of figure 3, south and west of the Patoka structural complex, also is indicated as a closed thick area, indicating that at depth this area is structurally low. The rapid thickening eastward from the Patoka structural complex is evidence that the DuQuoin monocline was formed during this interval.

The southeast trend of the isopach lines in the southernmost sections of T. 3 N., R. 1 E. is apparently caused by the reef structure of the Sandoval pool (sec. 4, T. 2 N., R. 1 E.).

Structure at the Base of the Glen Dean Limestone (Chester Series)

Figure 5, which shows the structure at the base of the Glen Dean Limestone, is probably the most nearly accurate map included in this report because it is based on more control points than the other maps. The structural low, south and west of the Patoka structural complex, is more detailed than on the other maps, the Patoka structural complex is shown more sharply, and the Patoka East structural complex is more sharply defined and its continuity is more clearly indicated.

There is a strong suggestion of structural saddles between the reef structures and the deformational anticlines. Southwest of the Fairman pool (secs. 23, 24, and 25, T. 3 N., R. 1 W.) another structural saddle is indicated. The subdued nose, apparent in secs. 13, 14, 15, 21, 22, 23, and 24, T. 3 N., R. 1 E., plunging approximately N. 75° E., is well indicated. As reef structures are known to occur in this general area, this high might be attributed to a reef structure. More intensive investigation, however, shows that the points known along this structure are uniformly high and that it plunges gently to the east. However, until more information is available, reef control for this structure cannot be discounted. There is a possibility that this high is a remnant of an early Paleozoic structural fabric that had later been folded along its axial crest. If this is so, it may originally have had a northwest trend. There are suggested northwest trends shown on these maps, especially in the western portions.

The high area in secs. 27, 33, and 34, T. 3 N., R. 1 W. may indicate a reef structure at depth. There is a slight suggestion of a northwest trend in this part of the area.

Thickness of the Valmeyer and Kinderhook Series (Mississippian)

The isopach map of the Valmeyer and Kinderhook Series (fig. 6) is significant, though based on sparse data. The thinning shown over the Patoka structural complex and parts of the Patoka East structural complex definitely points to pre-Kinderhook folding. The closed thin area centered at Boulder East (sec.

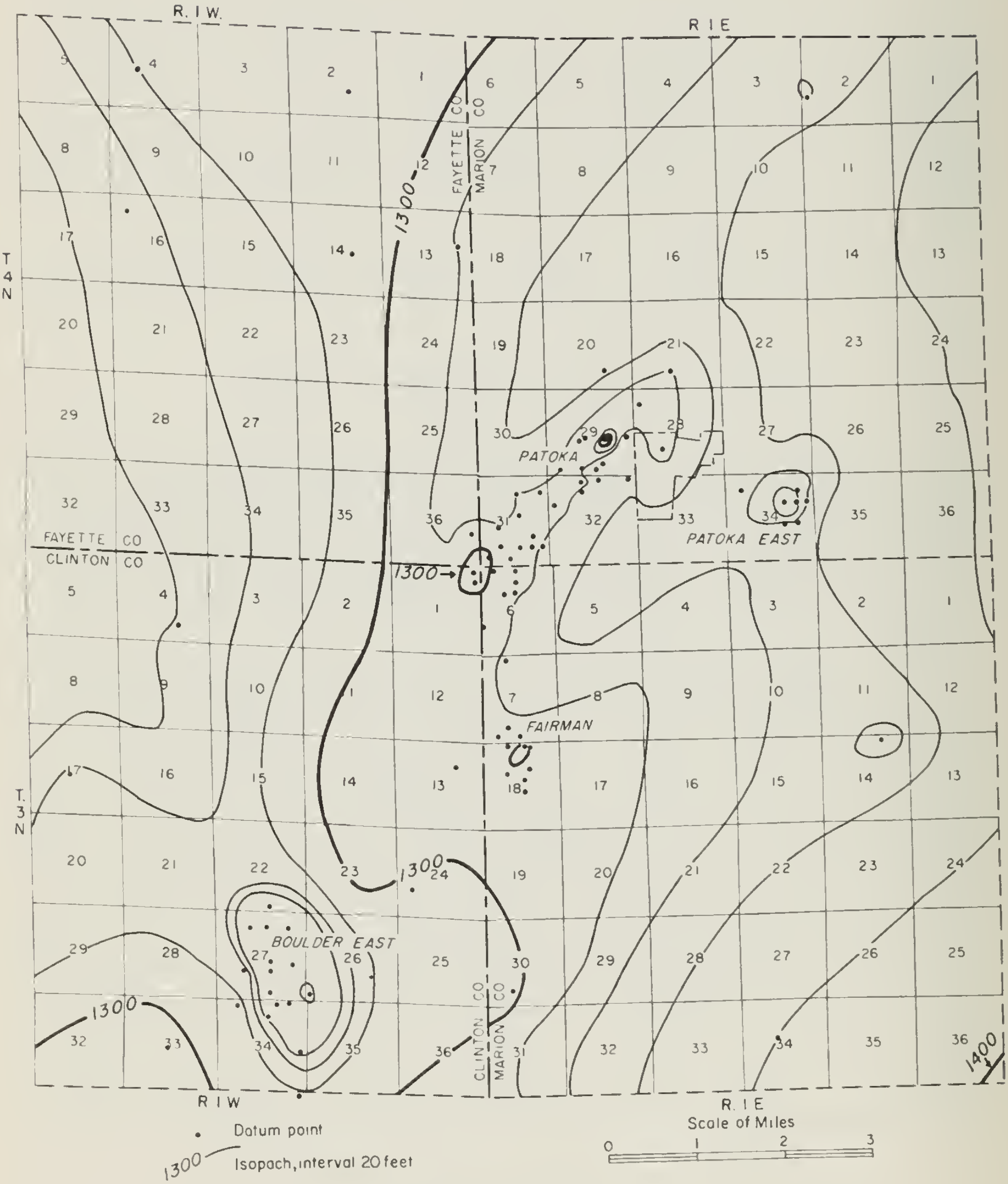


Fig. 6. - Isopach map showing thickness of the Valmeyer and Kinderhook Series (Mississippian).

27, T. 3 N., R. 1 W.) is sharp and appears to be similar to the thinning displayed by the reef structures at Patoka and Patoka East. The north-northwest trend of this structure, its broad flat top, and its possible relation to the deformational anticline shown on the Kimmswick, all differ in degree from the known Silurian reefs at Patoka and Patoka East. Its appearance, compared to those of other known reefs in the basin, certainly suggests a reef structure. However, the northwest-southeast trend possibly indicated in secs. 9 and 16, T. 3 N., R. 1 W. may be genetically related to it. If this is so, then an ancient, subdued, northwest structure may be responsible for the high where its axial crest is intersected by the axial crest of the northeast-trending Fairman deformational anticline. The thin spot shown in sec. 14, T. 3 N., R. 1 E. is indicated by a closed isopach line. Lack of control points causes this or any other interpretation of the structure to lose significance. The Patoka and Patoka East reef structures are well defined by sharp, thin areas.

The regional thickening from west to east is approximately constant across the position of the DuQuoin monocline, indicating that there was no significant development of that structural feature during the Mississippian period.

Structure on Top of the Lingle Limestone (Devonian)

The map showing the structure on top of the Lingle Limestone (fig. 7) is based on sparse data. Where datum points are lacking, the elevation of the Lingle Limestone was estimated from Ste. Genevieve points.

The interpretation of the Patoka deformational anticline is based on many points and is sharply defined. The Fairman deformational anticline has been interpreted as a nose rather than as a closed structure. The reef structures at Patoka and Patoka East are well indicated. The structure of the Patoka West pool, indicated as a terrace in figure 4, does not seem to diverge from regional dip at this depth. The structural low indicated in all previous maps also is indicated on this map, centered in sec. 11, T. 3 N., R. 1 W. The high in sec. 27, T. 3 N., R. 1 W., may be held up by a reef structure. The northwest-southeast "ridge" between secs. 17 and 34, T. 3 N., R. 1 W., may be a vestige of an ancient, northwest-trending, structural fabric. However, there is little supporting evidence for this interpretation. The slight nose shown in figures 3-6 in sec. 14, T. 3 N., R. 1 E., is shown as a broad, subdued nose. The structural embayment northwest of the Patoka reef structure is sharply indicated. The trough separating the Patoka and Patoka East structural complexes is clearly defined. The east dip from the DuQuoin monocline is essentially parallel to the dip indicated on figure 4.

Thickness of Devonian, Silurian, and Cincinnatian (Ordovician) Strata

The isopach interval between the base of the New Albany Shale and the top of the Kimmswick Formations (fig. 8) is significant, especially in the immediate vicinities of the Patoka and Patoka East structural complexes. The closed thick spots at Patoka and Patoka East clearly delimit the reef structures. The large closed thick area in the southern part of T. 3 N., R. 1 W., appears to show a reef structure. The thin areas along the crests of the anticlines indicate that the folding was pre-Devonian. Further discussion concerning the time of this folding appears below.

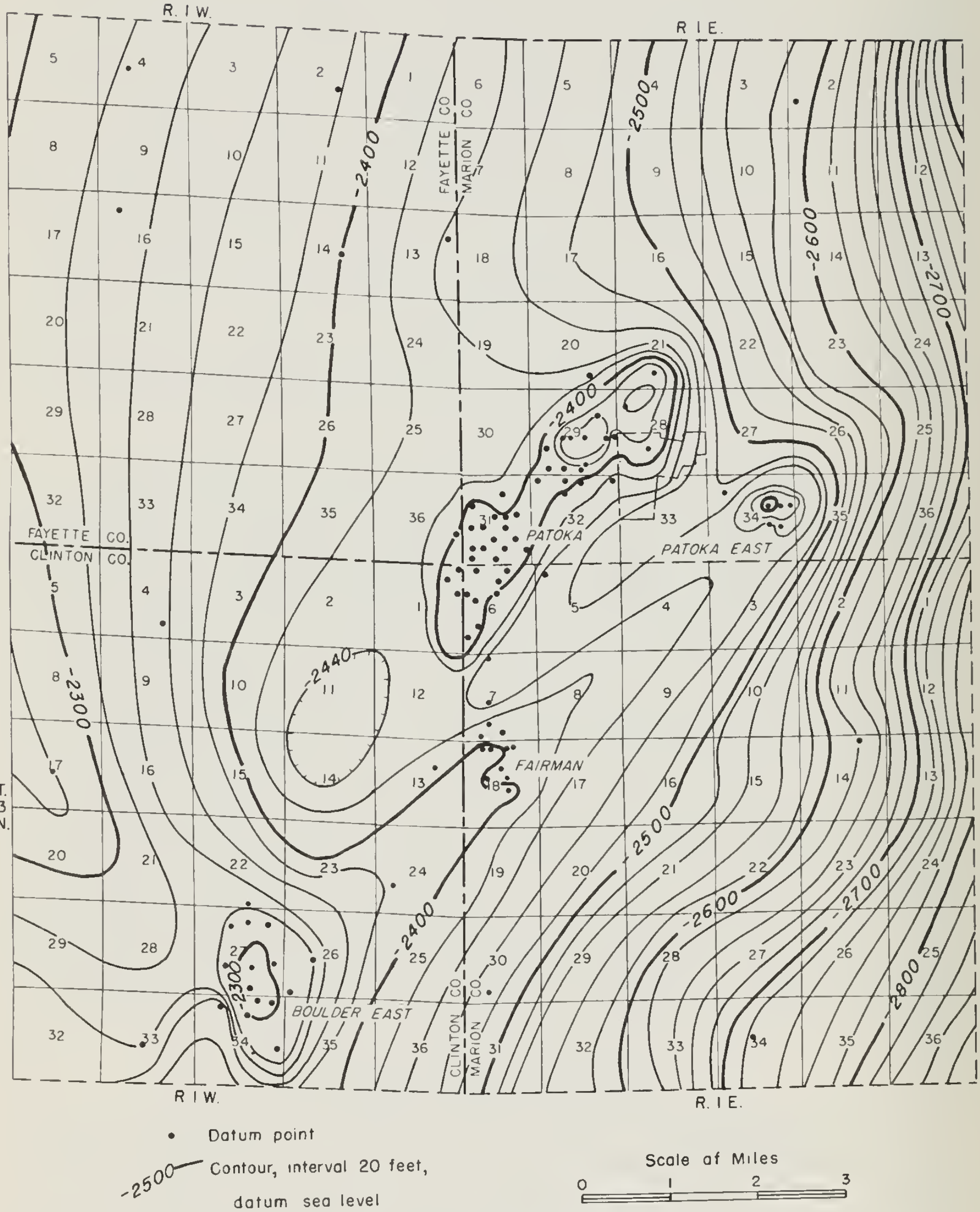


Fig. 7. - Structure map on top of the Lingle Limestone (Devonian).

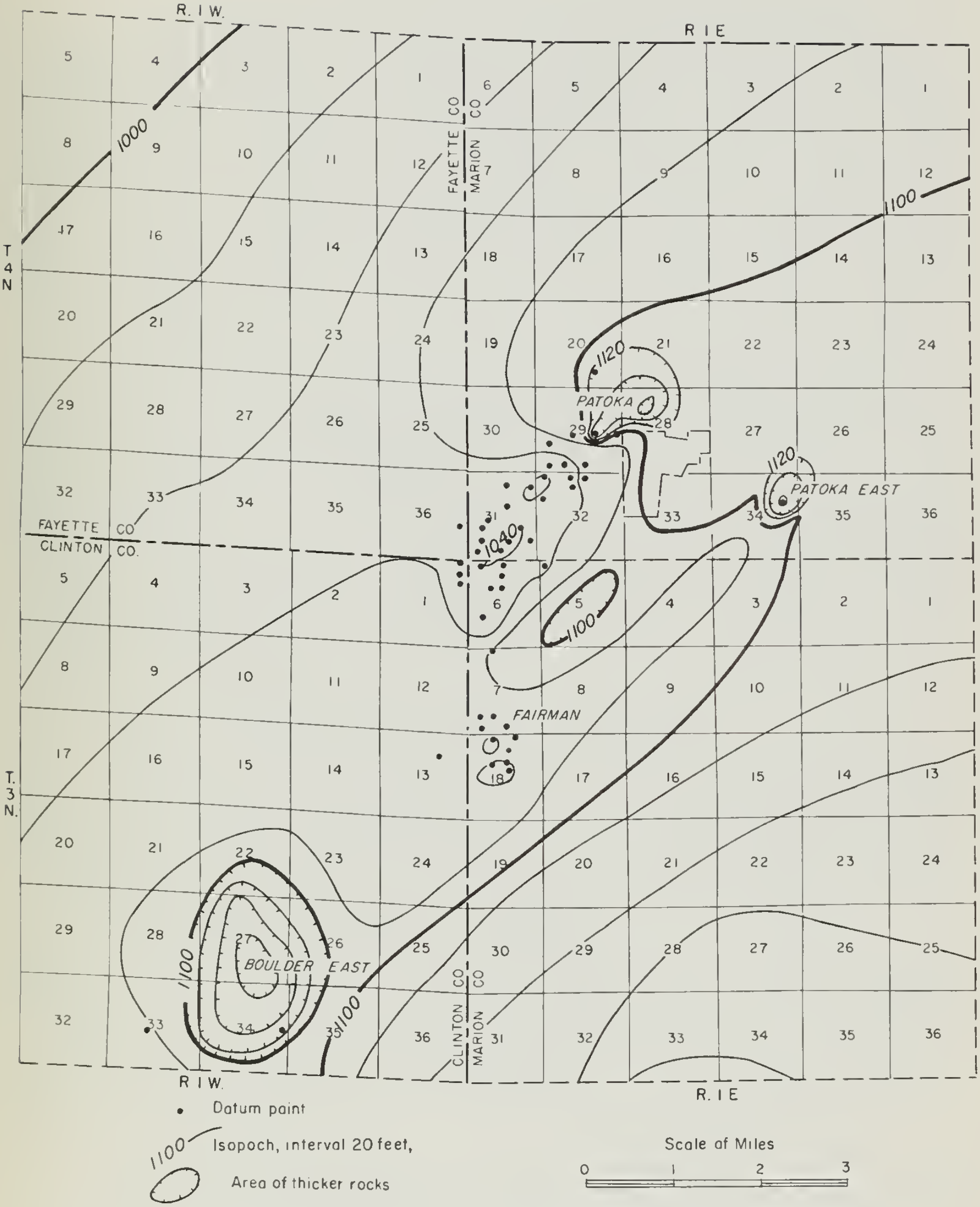


Fig. 8. - Isopach map showing thickness of Devonian, Silurian, and Cincinnatian strata (top of the Lingle Limestone to top of the Kimmswick).

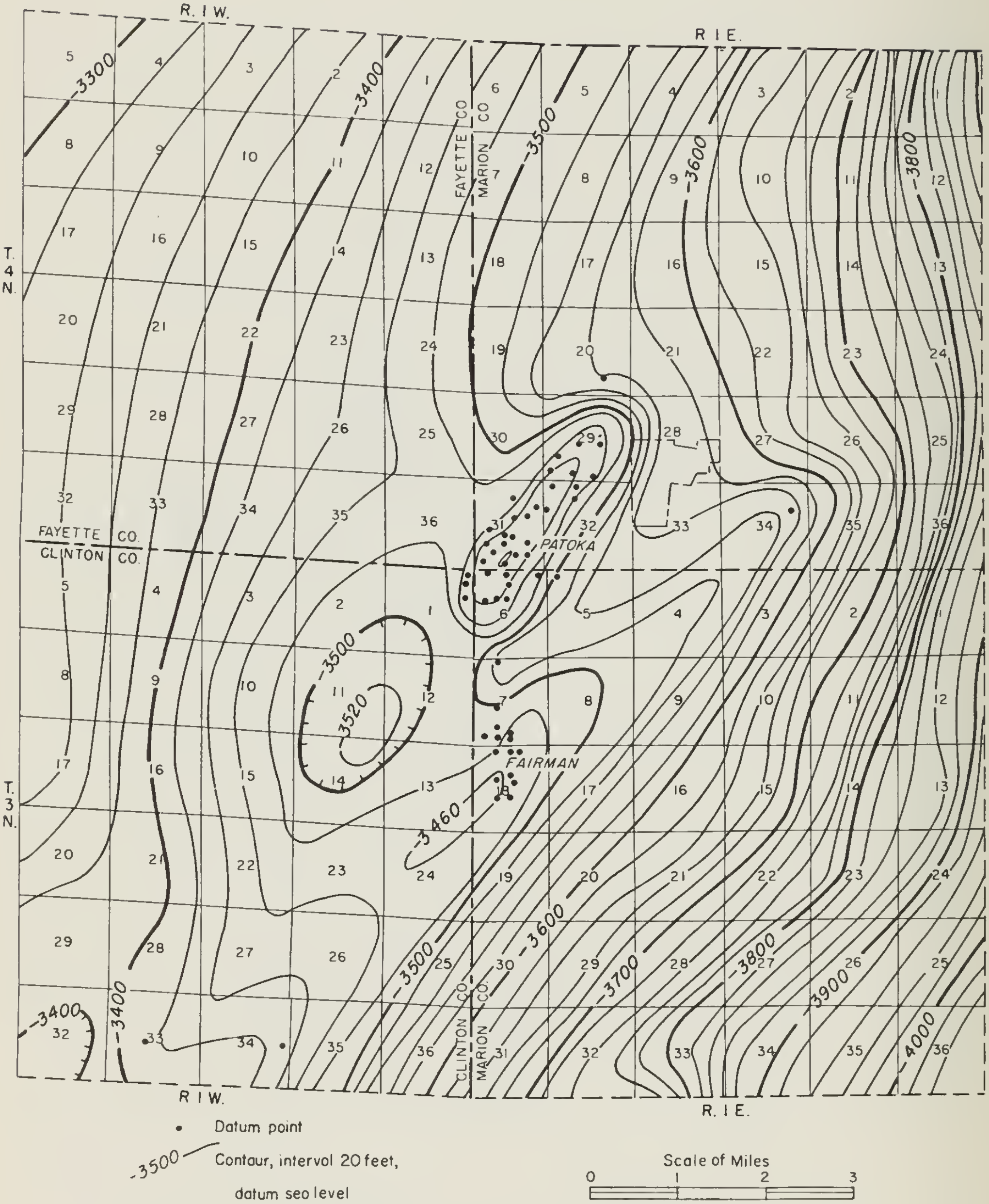


Fig. 9. - Structure map on top of the Kimmswick ("Trenton").

Structure on Top of the Kimmswick ("Trenton") Formation

The interpretation of the structure shown on top of the Kimmswick Formation (fig. 9) is based, to a great extent, on the isopach map (fig. 8).

In areas of no control, projection from the top of the Lingle Limestone was used. Consequently, the significance of figure 9 is centered mainly in the areas of the Patoka and Fairman deformational anticlines. These structures on this map are not complex structures, but deformational anticlinal folds. The Patoka deformational anticline plunges N. 35° E. and S. 35° W. The Fairman deformational anticline, as interpreted, is an elongate fold, plunging N. 45° E., with at least one saddle on its crest (sec 24, T. 3 N., R. 1 W.). The east flank of the Fairman deformational anticline seems to coincide, in part, with the DuQuoin monocline.

A subdued northwest trend appears to be present in the southwest quarter of T. 3 N., R 1 W.

In secs. 32 and 33, T. 3 N., R. 1 E., the contour lines reverse strike from southwest to southeast, possibly indicating a Patoka-like structure underlying the Sandoval reef structure. The possible reef-like structure in secs. 27 and 34, T. 3 N., R. 1 W. may indicate that the Fairman deformational anticline is not a continuous structure but consists of a series of small folds separated by saddles.

Figure 8 indicates that the deformational anticlines were, at least in part, pre-Lingle. The interval between the Lingle (Devonian) and Kimmswick (Ordovician) is thinner over the Patoka deformational anticline and seems to be thinner over the Fairman deformational anticline from sec. 24, T. 3 N., R. 1 W. to the Patoka East pool.

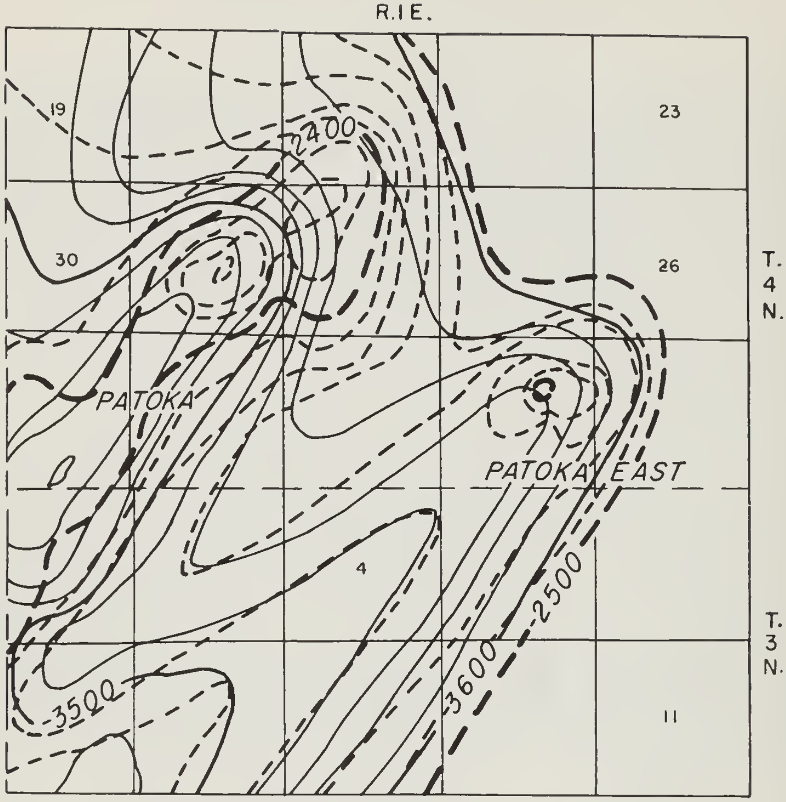
Comparison of the Structures Shown on the Lingle Limestone and the Kimmswick Formations

The structure maps on the Lingle Limestone and Kimmswick formations, in the vicinity of the northeast zones of the Patoka and Patoka East structural complexes, are shown superimposed on figure 10. The map indicates that the drilled Silurian reefs are located on the noses of the deformational anticlines. The relationship is so striking that one is forced to consider that the reefs may be a direct result of the presence of the structure.

If so, the structures must be pre-reef or pre-Silurian, a conclusion borne out by the isopach maps in this report, all of which show thinning over the anticlines.

John Van Fossen of the Kewanee Oil Company has supplied information about the porosity of the Kimmswick Formation in the area of the Patoka deformational anticline. The data are not conclusive, but it appears that the areas of highest porosity are along the crest, and the lowest porosities are on the flanks or off structure.

The higher porosities on the crest may be the result of straining and fracturing during folding, or to differential solution along the crest. It also is possible that the zones on the crest are unlike those on the flanks, but the uniformity of the electric log characteristics would discount this possibility. Finally, the different porosities may be due to differential weathering during post-Kimmswick and pre-Maquoketa times. If this is so, then the anticlines must have been already developed by Maquoketa time.



KEY

- 2400 – – – Contour on top of Lingle (Devonian) interval, 20 feet

- 3500 ——— Contour on top of KIMMSWICK [redacted] (Ordovician) interval, 20 feet

Fig. 10. - Relation of deformational anticlines to Silurian Reefs.

Other known Silurian reefs outside of the area of this report are similarly situated with respect to "Trenton" structures. The Tonti reef structure (secs. 33 and 34, T. 3 N., R. 2 E.) is north and slightly east of the north nose of the Salem structure. The marine reef structure (T. 4 N., R. 6 W.) may be closely associated with a "Trenton" structure. The Sandoval reef (T. 2 N., R. 1 E.) may be similarly situated on a northeast-trending "Trenton" structure.

Figure 11 is a simple cross section along the crest of the northeast nose of the Patoka structure traversing the anticline and reef part of the structure. The base of the Glen Dean Limestone, top of the Lingle Limestone, and top of the Kimmswick Limestone are represented. The subdued character of the structure as reflected by the Chester stratum is apparent. The saddle between the anticlinal nose and the Silurian reef is indicated distinctly by the Devonian strata (Lingle Limestone). The relation of the Silurian reef to the "Trenton" anticline is apparent.

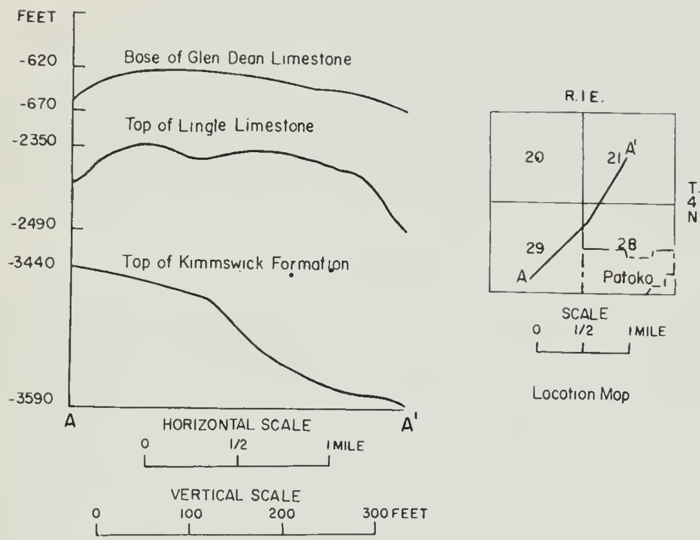


Fig. 11. - Cross section across the nose of the Patoka structural complex.

REEF DEVELOPMENT

The Patoka reef is attached to the northeast nose of the Patoka deformational anticline as shown on the Kimmswick Formation. That the reef developed there because the anticline had been a ridge on the Silurian sea floor seems likely for the following reasons:

1) As corals can live only in the zone penetrated by light, the reef's position on the ridge must have been within that zone because coral fossils are present in the reef.

2) An adequate supply of oxygen is needed for coral growth. During daytime, the algae associated with the corals could have supplied oxygen, but during times of no sunlight some other supply of oxygen must have been present. Kuenen (1950, p. 418) reports that currents and wave action favor coral growth as long as turbidity remains low, because free oxygen would be supplied to the organisms through aeration. The reef at Patoka is situated north of the maximum structure high and therefore north of the greatest turbidity. It was, however, possibly close enough to the maximum turbidity for an adequate oxygen supply, because prevailing winds (and currents) were from the south (Lowenstam, 1950) or southwest (Meents, personal communication, 1958), but far enough from it to allow the organisms to develop.

3) The high altitude of the Kimmswick anticline in the submarine topography also would be advantageous because mud and silt would not tend to accumulate on the high ridges. Kuenen (1950, p. 419), reporting on present reefs, states, "It is only because of the existing topographical eminence that a suitable foundation closer to the surface is offered to corals." The corals could not develop in the fine muds and silts that would be found off the structural highs.

The Patoka East reef seems to be similarly situated with respect to a different anticline on the Kimmswick.

From very meager information at hand, it seems possible that the Sandoval reef may be similarly situated in respect to another "Trenton" structure.

The possible reef structure at Boulder East (centered in sec. 27, T. 3 N., R. 1 W.) shows a very close relationship to an anticlinal nose, as interpreted by the author.

CONCLUSIONS

1) Isopach and structural maps of Pennsylvanian and Mississippian rocks in part reflect the buried reef structures at Patoka and Patoka East and the associated deformational anticlines on the Ordovician rocks. Not all structures of the Pennsylvanian sediments reflect deeper structures. Many irregularities in Pennsylvanian structure appear that do not exist in the older rocks, and these may be due to the many lithic changes and differences in compaction values.

2) The Patoka deformational anticline is a small, doubly plunging fold.

3) The reef at Patoka is attached to the northeast nose of the Patoka deformational anticline as shown on the Kimmswick Formation. A similar association between the known Patoka East reef and the hypothesized Fairman deformational anticline seems apparent. These folds apparently were ridges on the Silurian sea floor and, as such, were controlling factors in reef development.

4) Evidence at hand indicates an elongate, northeast-plunging deformational anticline on the Kimmswick Formation that supports production at Fairman from the Kimmswick Formation and Mississippian production at Patoka South and Fairman.

5) It appears that Kimmswick production could be extended northeastward and southwestward from the Fairman pool.

6) The Patoka and Fairman deformational anticlines were developed, at least in part, post-Kimmswick (Ordovician) and pre-Silurian.

7) Reef structures and deep folds are well indicated by the altitudes of Chester strata.

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