SOME FEATURES OF THE CINCINNATI ARCH AS SHOWN BY GEOLOGICAL CONDITIONS IN AN INDIANA GAS FIELD.

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The eastern Indiana oil and gas producing area, locally known as the "Trenton field", is located chiefly on the sides and partly on the top of the northwestern extension of the Cincinnati arch. The conformation of the arch has been a matter of considerable speculation. Conceivably the arch may be a single simple fold with a fairly uniform structural outline. On the other hand it is possible to conceive its being a geanticline with many minor undulations or structural irregularities. Both of these views have been expressed but apparently the simple fold has found greater favor.

Difficulties in the solution of the problem arise from several sources. A study of bed-rock strata has been impossible because of glacial covering. In the study of the meagre evidence from sub-surface records there appeared an uncertainty as to the presence or absence of major unconformities and of later differential movements. In the presence of accurate logs from closely spaced wells, the solution of the problem would not have been difficult.

It is evident that in the case of a simple fold containing a sand of uniform thickness and degree of porosity the gas, oil, and water will be arranged according to their specific gravities. Departures from this order of arrangement may be assigned to irregularities in structural conditions, such as are present in a geanticline, to lack of water pressure, or to variations in the porosity of the petroliferous sand. In a general way the distribution of gas and oil in the Trenton field indicates gravity control in a simple fold. However, there are irregularities of distribution and these have been assigned commonly to differences of porosity. An alternative hypothesis will be presented in this discussion.

Information regarding sub-surface conditions has been obtained by the writer from a number of localities. One of these areas is located partly in Howard and partly in Tipton counties. Through the kindness of the Indiana Natural Gas and Oil Company the logs of a large number of wells distributed through the area were obtained for study. It was found that the close spacing of the wells in certain parts of the area made it possible to make certain deductions regarding structural conditions. The following discussion applies to the area selected for study.

Location. The area lies in the northern part of Tipton County and in the southern part of Howard County between Kokomo and Tipton. The city of Sharpsville is near the center of the area. The size of the area is about 153 square miles.

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5—39184

Topography. The surface of the region is that of a very level plain. The maximum difference in relief is 95 feet. The highest surface elevation is 917 feet above sea level. This point is located in the southwestern part of the area in Section 8, T 21 N, R 3 E. The lowest point is about three miles southeast of Kokomo in Section 16, T 23 N, R 4 E. The elevation is 822 feet above sea level. The slope between these points is a gradual one.

Since the area as a whole lies within the Tipton till plain it is probable that at the close of the late Wisconsin glacial stage the surface was practically level and that the relief which it has at present has been developed by post-glacial erosion. The surface topography bears little relation to structural conditions. The greater part of the highest relief is over synclinal areas though the highest point lies above an anticlinal area.

Stratigraphical conditions. The Pleistocene and Recent deposits occupy the surface of the area. They consist of sands, gravels, clays and loams. The maximum thickness of the drift is 287 feet and the minimum is 35 feet. The drift includes both Illinoian and Wisconsin drift materials. The Pleistocene deposits rest on the eroded surface of rocks of Silurian age. Preglacial erosion has deeply trenched the surface of the Silurian but the deposition of the drift filled up the depressions in the surface.

Silurian rocks. Only the upper part of the Silurian rocks are exposed at any point in the general area. In the area under discussion they are not exposed. According to well records they consist of shales and limestones which, in the vicinity of Kokomo, have a total thickness of 360 feet. From the log of the Wm. Moore well in the vicinity of Kokomo in Center Township the following Silurian section was obtained:

Silurian Section From Moore Well.

Limestone, thin bedded	10 feet.
Limestone, bluish, more massive	80 feet.
Limestone, white, shaly	95 feet.
Limestone, bluish	65 feet.
Shale, calcareous	35 feet.
Limestone, gray	75 feet.
Total	360 feet.

Ordovician rocks. The Silurian rocks rest upon the surface of the rocks of the Cincinnatian group of the Ordovician system. The rocks of the Cincinnatian group consist of thin bedded limestones and shales. The total thickness of the group in the Moore well referred to above is 511 feet.

STRUCTURAL FEATURES.

In making a study of the structural conditions two key horizons were used. The first from the surface was the basal contact of the Silurian limestone with the shale of the Cincinnatian group. The highest

structural point obtained by using this horizon is 444 feet and the lowest 301 feet above sea, giving a range of 143 feet between highest and lowest structural points. The highest productive point is 431 feet above sea and the lowest 312 feet above sea. The range in altitude of productive area is 119 feet on the structures. The amount of structural height above productive area is only 13 feet.

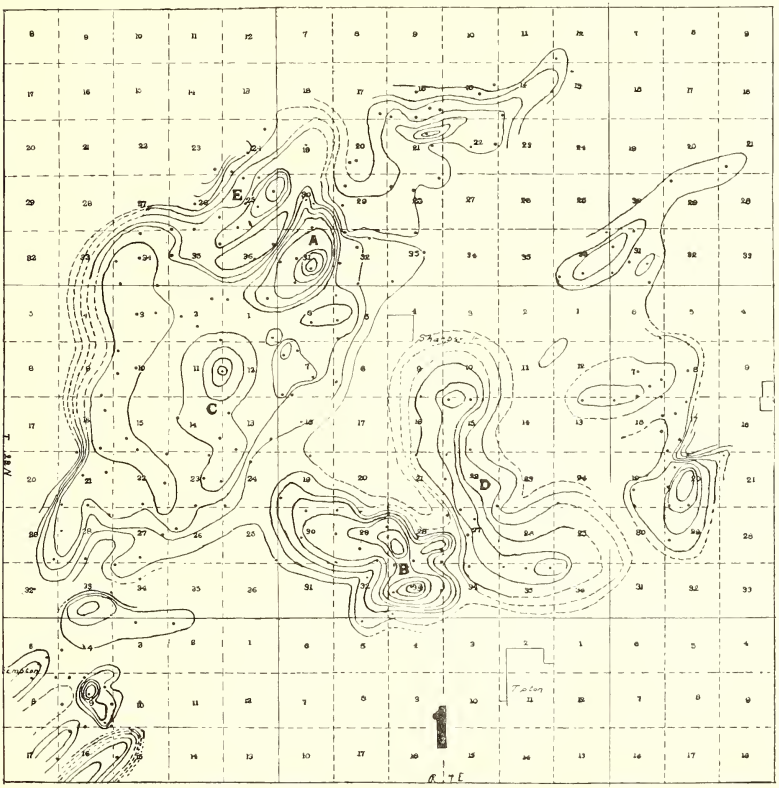

Fig. 1. Showing irregularities developed on the surface of the Cincinnatian shales by using the Silurian-Ordovician contact as a key horizon. The contour interval used is 20 feet.

Trenton key horizon. Using the contact between the Cincinnatian group and the Mohawkian (Trenton) limestone as a key horizon the highest productive point is 61 feet below sea and the highest non-productive point 68 feet below sea. The lowest productive point is 14 feet below sea. The range in altitude of productive area is 79 feet as compared with 119 feet on the upper key horizon. The difference in elevation between production and non-production on the structure is seven feet on the higher parts of the structures and only three feet on the lower parts of the structures.

STRUCTURES.

The highest structures in the area are included in the following list:

Structure A—located in Sections 30, 31, 32, mainly, in R 4 E, T 23 N.

Structure B—located in Sections 28, 29, 32, 33, mainly, in R 4 E, T 22 N.

Structure C—located in Sections 11, 12, 13, 14, mainly, in R 3 E, T 22 N.

Structure D—located in Sections 10, 15, 22, 27, 35, R 4 E, T 22 N.

Structure E—located in Sections 25, 30, mainly, in R 3 E, and R 4 E, T 23 N.

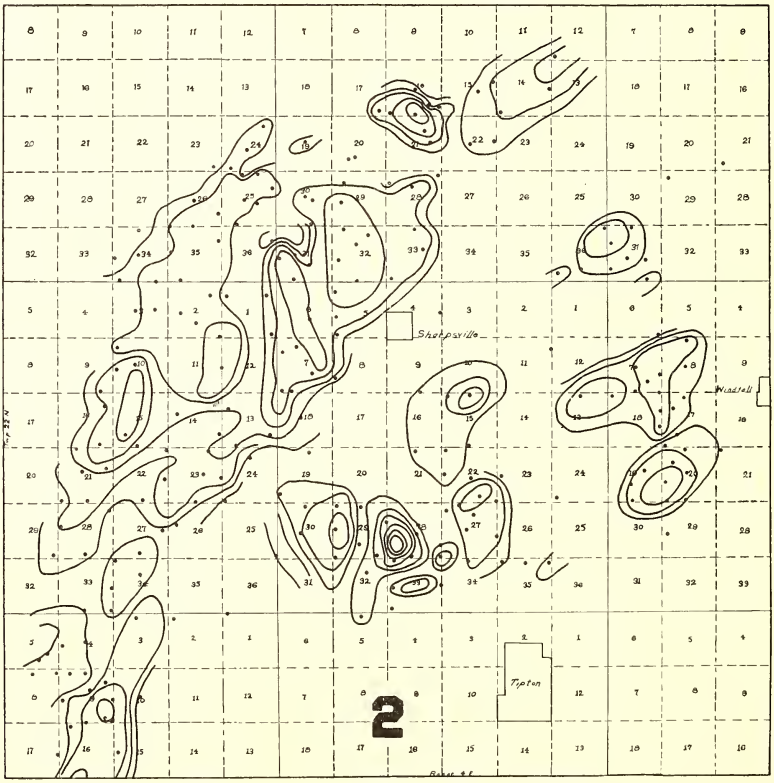

Fig. 2. Showing irregularities developed on the surface of the Mohawkian (Trenton) limestone of Ordovician Age. The key horizon used is the top of the Trenton limestone. The contour interval is 10 feet.

Structure A. On Structure A production was obtained at elevations (using the first key horizon) between 350 and 408 feet above sea. Above and below these limits, so far as our records go, there was no production. On the structure within these limits there were found five

producing wells and two non-producing. Non-producing is not used in the sense that no gas was found but with the meaning that no commercial quantities were obtained. Structure A covers a little more than one square mile of surface.

Structure B. This is a compound structure consisting of three parts. The highest part reaches an elevation of 431 feet above sea, another part attains a height of 421 feet and a third of 405 feet above sea. The surface of the structure between these high points is slightly lower. The main part of the structure occupies an area of about two square miles. Production was obtained from an altitude of 370 to 431 feet on the structure. There were ten producing wells and four non-producing.

Structure C. This is a simple somewhat elongate structure, the highest point of which is 410 feet above sea level. The main part of the structure occupies about one square mile of surface. Production was obtained between 382 and 410 feet above sea. Within these limits were found five wells of commercial importance and four that were not.

Structure D. This is a compound structure consisting of two high points both of the same altitude. They are separated by an horizontal distance of three and one-half miles. They are joined by a ridge the upper surface of which is about 20 feet lower than the high points. More closely spaced wells on this structure might reveal other points of equal or greater height than those at the extremities of the ridge. The productive area on this structure extends from 384 to 401 feet above sea. The number of productive wells between these limits was ten and the non-productive wells was four in number.

Structure E. This is a simple structure occupying about one square mile of surface. Its highest point is about 388 feet above sea. Production was obtained between 354 and 388 feet above sea on the structure. There were eight producing and no non-producing wells on the structure.

Other Structures. There are 12 other structures within the territory covered by the well records. These structures are partly or wholly outlined. They show no marked differences from those described.

Possible Causes of Irregularities. The irregularities of the surface of the Cincinnatian shales might be accounted for on the basis of structural conditions only. It would seem however if they were formed by folding that they should be less pronounced than those on the surface of the Trenton but the reverse is true. It might be suggested that these irregularities were due in part to sub-aerial erosion. However, the trenching which is so generally present in the sub-aerial erosion of soft rocks is apparently not present. Another suggestion which might be made is that the high points are due in part to sub-aqueous erosion. If erosion of any type is responsible it would seem that sub-aqueous erosion best conforms to the conditions of the irregularity produced. The mud-lump type of origin may be objected to on the ground

that in a general way the high points on the higher horizon correspond to those on the lower.

It is probable that when the Cincinnati arch in the region of Cincinnati was brought above the sea the northwestern extension across Indiana was defined as a sub-aqueous ridge. Assuming that this be true it is conceivable that the surface of this ridge had the general irregularities as to outline as those existing on the surface of the Trenton limestone. It is apparent that this ridge did not reach the surface of the water since there is no evidence of sub-aerial erosion in the region under discussion.

Assuming that the folding was Post-Silurian then an incompetent bed would be folded between two competent beds. It would seem to the writer that under those circumstances the folds which would be produced in the incompetent layer would be regular in outline. The structures developed on the Cincinnatian shales are not of this type as has been explained in previous pages.

Gravitational compaction may have had an influence in producing the irregularities if it be assumed that the ridges on the rocks below the shales were developed, prior to their deposition, either by folding or by erosion.