

NOTES ON THE WATERLOO ANTICLINE

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The Waterloo anticline is located between the towns of Columbia and Waterloo, in Monroe County, Illinois, about 28 miles southeast of St. Louis. The structure was first worked out by Dr. Stuart Weller in connection with his geologic mapping of Monroe County for the Illinois State Geological Survey. In the fall of 1920 a heavy oil was encountered in the Kimmswick limestone in a well drilled for water by the Waterloo Condensed Milk Company. Shortly afterwards two press bulletins were issued by the State Geological Survey, the first by Mr. H. E. Culver, and the second by Mr. L. A. Mylius, in which the structure was delineated and recommendations made for drilling. This is the most recent case where the Survey has called attention to favorable field conditions and directed successful exploration.

Up to the present time there have been 55 wells drilled on the anticline, and of this number 33 are producers, 12 dry with a showing, 3 incomplete, and 7 dry. Wells with good locations on structure come in at from 75 to 125 barrels, but soon drop off to 25 or 50 barrels per day. They do, however, make good consistent pumpers, and because of the nature of the pay are likely to be long lived.

THE STRUCTURE OF THE WATERLOO ANTICLINE

The structure is that of a long, narrow, sharp crested asymmetrical anticline, extending approximately from north to south, with its maximum width of about one mile near the north end, and tapering abruptly to the north, but extending as a long, narrow fold for about $3\frac{1}{2}$ miles to the south. The total length of the anticline is about five miles.

The west flank is by far the steeper side with an average dip, as indicated by structure contours on the Kimmswick limestone, of about 10° to the west. In the vicinity of the producing area it is cut by a normal fault with its upthrow side to the east, which probably dies out into a monocline to the south. This fault brings inclined

Warsaw beds in contact with almost horizontal Chester beds. Its presence is further substantiated by a well drilled apparently on the fault plane or close to it, which encountered considerable "creviced rock" and clear transparent quartz, as well as a rather unusual succession of limestones.

The east side of the anticline is much less steep than the west, and has an average dip, as indicated by structure maps, of about 4° to the east.

THE PRODUCTIVE AREAS

The greater part of the production in this field comes from a tract about a mile long and a third of a mile wide, which comprises the top of the anticline. Most of this area has already been drilled, but there is a possibility of the extension of production somewhat farther to the north and south, particularly along the axis of the anticline.

There has been a little production about three miles south of the main pool in section 24 on what appears to be a narrow terrace, or slight flattening of the pitch of the main anticline. The wells located on the top of this terrace come in at from 5 to 10 barrels, and those slightly off on the sides, though dry in the Kimmswick, show gas in small quantities in what is probably the Keokuk-Burlington.

Between the large and small producing areas and also south of the latter, all wells drilled on the axis of the anticline have showed oil, but none in sufficient quantities to make profitable wells.

THE GEOLOGIC COLUMN

The geologic column in this area is relatively simple, but some interesting features are brought out in studies of the well cuttings. The formations may be described briefly as follows:

THE MISSISSIPPIAN SYSTEM

St. Louis Limestone:

The St. Louis limestone is a fine grained, dense, hard, compact rock which locally contains numerous nodules

of chert. It is entirely eroded from the top of the anticline and is exposed well down on the flanks. The maximum thickness shown in well records is 185 feet.

Salem Limestone:

The Salem limestone, like the overlying St. Louis, is also eroded from the top of the anticline. Where exposed, it consists of a fine and coarse grained, moderately hard, gray-white and speckled limestone. Locally it contains chert, and is commonly oolitic. As noted from well records its thickness varies up to 140 feet.

Warsaw Limestone and Shale:

The Warsaw outcrops on the flanks of the anticline, but it is entirely eroded from the crest. It consists of gray and buff, crystalline limestone, moderately hard, and locally argillaceous, and interbedded with thin layers of shale. In the upper beds of the formation *Spirifer washingtonensis* and *Productus magnus* are abundant. Its thickness ranges up to 125 feet.

Keokuk-Burlington Limestone:

The Keokuk-Burlington is the oldest formation exposed on the anticline. It consists of coarsely crystalline, or granular, white limestone with much interbedded blue-white chert. Its thickness varies from a few feet on the top of the anticline to about 240 feet well down on the flanks.

Kinderhook Limestone and Shale:

The Kinderhook formation has two phases, the upper shaly phase and the lower limy phase. The upper phase is not every where present; in fact it is more commonly absent than present, and so far as known does not outcrop in the vicinity of the anticline. It appears more commonly in the logs of wells drilled near or on the axis of the anticline, and has a thickness of from 32 to 110 feet, with an average of 70 feet for the eight wells in which it is logged.

As indicated by the disparity between the maximum and minimum thicknesses, the shaly portion of the Kin-

derhook is largely eroded and the declivities of the eroded surfaces are apparently abrupt and sharp since a horizontal distance of a few hundred feet may make differences of 60 or more feet in the thickness of the shale or may even account for its entire disappearance.

The lower phase, the Fern Glen limestone, averages about 30 feet in thickness, but with extremes as low as 11 and as high as 60 feet. The limestone is coarse grained and of variegated shades of brown-red, dull red-purple, pink, green, and white. The red and purple limestones have a dull, dead lustre, while the remaining pink, green, and white have the vitreous lustre of crystalline calcite. The red color of the limestone is probably due to minute particles of red ferruginous shale and hematite. Locally the Fern Glen contains chert, crystalline calcite, and commonly the top or medial portions contain thin beds of red, gray, or greenish-gray shale. Where the formation is thick, however, it is roughly divisible into the upper and lower red limestone beds, with intermediate beds of gray or green shale.

In the vicinity of the anticline, the drillers estimate the interval between the top of the Fern Glen and the top of the Kimmswick as 200 feet. As a rule this applies to the interval between the top of the "red rock" and the first showing of oil below the "black shale". Logs bear this out, and in almost every case the interval between the two horizons mentioned is from 200 to 220 feet. This is rather surprising when it is remembered that the Devonian in this area is unconformable above and below, and varies from a few feet up to 75 feet in thickness, and that the Trenton cap, the Fernvale, also is not of constant thickness.

THE DEVONIAN SYSTEM

Judging from the number of logs which do not record the Devonian limestone, it is not every where present. Whether it has been logged with the Fern Glen or really is absent can not be stated definitely. However, in the 20 logs in which it is recorded, it has a range in thickness of from 20 to 75 feet and averages 40 feet.

The limestone is gray-white, coarse grained, and moderately hard, and is unconformable with the beds above and below.

THE ORDOVICIAN SYSTEM

Maquoketa shale:

The Maquoketa is a dense, dark gray shale. Its thickness, as indicated from well logs, averages about 85 feet on the top of the anticline. Well down on the flanks of the anticline its thickness is as great as 145 feet.

Fernvale limestone or "Trenton Cap":

Figures on the thickness of the Fernvale are very difficult to obtain, primarily because it is followed below by a limestone, with which it is commonly included by the drillers. This is not surprising because locally the top of the Kimmswick "tightens up" so as to be difficult to distinguish from the Fernvale without careful examination. However, from the best available information, the average thickness of the Fernvale may be considered about 12 feet. The minimum thickness noted is 2 feet, in the log of a well drilled approximately on the axis of the anticline, and the maximum thickness of 29 feet, somewhat off on the east side of the anticline. The Fernvale is a dense, fine grained, hard, brittle, thin bedded, white limestone.

Kimmswick limestone ("Trenton"):

The Kimmswick is a coarse grained, moderately porous, coarsely crystalline, white limestone, and tests above 95 per cent calcium carbonate. When bailed out from a well it resembles very closely a true sand, and is so called by the drillers. Particularly is this so when the limestone does not contain oil, and is therefore pure white. The coarsely crystalline character and porosity make the Kimmswick a good oil reservoir, though locally it is rather "tight", particularly in its upper portion, and well down on the sides of the anticline. The top of the Kimmswick is irregular and unconformable with the formation above.

THE WELLS

In general, the wells in this area are drilled to a depth of between 475 and 550 feet, depending on the elevation of the curb of the well. The greatest difficulty in drilling is encountered in going through the cherty Keokuk-Burlington, and in some cases through the Maquoketa, which breaks up easily but will not mix with the water in the hole and is therefore difficult to drill through. At the present time wells are put down in from a week to 10 days, barring delays due to the failure of the drilling machinery. The general procedure is to drill the wells until the sand begins to show the first indications of water. On the crest of the anticline this means a drilling of about 50 feet into the Trenton before water is struck, while in producing wells off the axis water is usually encountered at about 30 feet. There are apparently no formations which are consistent aquifers in any one particular horizon. Parts of the Warsaw and Keokuk-Burlington, however, are reported by drillers to be creviced, and from such portions of these formations there is the greatest influx of water into the hole above the Maquoketa.

THE SOURCE OF THE OIL

In all probability the thick Trenton limestone and the Maquoketa shale are the formations in this area from which the oil has come. It is not an uncommon thing to encounter a strong odor of oil or even a little black oil in drilling through the Maquoketa shale. While this fact in no way proves that the Maquoketa was one of the sources of the oil in the Kimmswick it at least indicates that the Maquoketa may well have furnished some of the oil now found in the Kimmswick.

The oil which has accumulated in the Waterloo anticline probably migrated largely from the east and southeast. The Valmeyer anticline shuts off migration from the south and southwest, a syncline between the Waterloo anticline and the Mississippi River bluffs excludes extensive migration from the west, and to the north other smaller folds probably have acted as barriers preventing marked migration from that direction.

THE OIL

The oil secured in the Waterloo field is about 28° Beaumé gravity, with a high coke residue. After this residue is removed, however, the remaining oil gives a very high yield of the lighter distillates. It is black oil and contains a relatively small amount of gas and sulphur. The oil is steamed and then run into tank cars in which it is transported to the oil refineries at Wood River. The production at the present time is about three tank cars per day, and the selling price of the oil is \$1.75 per barrel.