

ART. XXX.—*On the Origin of the Rock Pressure of the Natural Gas of the Trenton Limestone of Ohio and Indiana*; by EDWARD ORTON.

DURING the last five years, there has been developed within six counties of northwestern Ohio, the most important single source of petroleum now known in the United States. During the same time, within the same territory and from the same geological horizon, several separate gas fields of extraordinary vigor and volume have also been brought to light. Following these surprising developments in Ohio, similar discoveries of gas have been made in the contiguous districts of northeastern and central Indiana. The new gas field of this last-named State, is by far the largest continuous gas field known in the world, its original area being not less than 2000 square miles.

The stratum which has yielded these remarkable supplies is the Trenton Limestone, one of the best known elements in the geological scale of North America. Although some phases of its outcrops had long been recognized as petroliferous, no one was prepared for its present enormous production. From single wells, 5½ inches in diameter, 5000 barrels of oil have flowed in a day, and to at least one well a total production of 200,000 bbls. is already credited. The gas wells of the formation are equally prolific. The maximum production thus far has been recently reached in an outflow of 33,000,000 cubic feet a day from a single well. A score of wells can be named, each of which exceeds in its daily flow 10,000,000 cubic feet of gas.

It is well known that the oil market of the country is in no sense an open market in which prices can freely adjust themselves to values. The severest possible repression has been imposed upon the production of the Trenton limestone, by fixing and holding the price of the oil derived from it at 15 cents a barrel, but the inherent vitality of the new source is shown in the fact that even at this rate more than 10,000,000 barrels were brought to the surface in 1889. Natural gas derived from the same formation is now furnishing all of the fuel and much of the artificial light that is used by a population of at least 500,000 people within the districts named

above, while an extraordinary volume of manufactures has been established on the new source of power.

The exploitation, upon which the remarkable developments above indicated are based, has furnished better opportunities in some respects for studying the phenomena and deducing the laws of the accumulation of petroleum and gas than any other American field has supplied. In the first place, the surface of the country in which the drilling has gone forward is so nearly level that all of the wells can be easily referred to a common base, as for example, to mean tide; in the second place, the series of strata penetrated by the drill is so uniform and so well marked that sharp and accurate determinations of all the important facts of stratigraphy are possible, and in the third place, the facts of structure are free from all complications, so that the effects due to them can be clearly and readily followed.

But a single one of the laws of the production of gas and oil as brought to light by this recent experience will be considered in the present paper, that, namely, pertaining to the *rock pressure* of gas; but before taking up this subject, a few preliminary statements, involving some of the laws already recognized, are required.

Preliminary Statements.

1. The gas and oil of the Trenton limestone are held in porous portions of the stratum. Neither caves nor fissures have been found by the drill and none are necessary.

2. The porosity of the limestone is due to the dolomitization which it has undergone. The portions of the stratum thus replaced seem to have been originally crinoidal limestone of a good degree of purity. The spaces left by imperfectly interlocking crystals give the rock great storage capacity, as great probably as the coarsest sandstones possess.

3. The porous beds are distributed through the uppermost portions of the stratum. None have been found as low as 100 feet below the surface, and almost all occur at less than half this depth. Several consecutive beds of dolomite, separated by ordinary and generally impure limestone, are occasionally found in the section. These petroliferous beds commonly range from seven to ten feet in thickness: they rarely rise to fifteen feet. Without dolomite in the Trenton limestone there is no petroleum. The dolomitized regions of the Trenton limestone are exceptional. They appear to extend from central Ohio northward through Michigan and they certainly extend westward through Indiana. To the south and east of these regions, the Trenton limestone lacks this character and is unproductive as to gas and oil.

4. The gas and oil are separated in every division of the field where both occur by lines of geographical level. Proper relief of the porous rock in the shape of arches or terraces is indispensable to gas fields and oil fields. The more pronounced the forms and the amount of the relief, the greater the accumulation.

5. Salt water or bittern is invariably found at a depth, constant for each subdivision of the field, in the lower levels of the porous rock, constituting a dead line for the oil and gas. The water is directly in contact with the oil or in the absence of oil, with the gas that is held in the arches or terraces, as is proved by the behavior of wells on the margins of the field. It is highly mineralized, having a specific gravity of 1.1.

6. When a well is drilled outside the dead line, the salt water rises more or less promptly as soon as the porous bed of the Trenton is penetrated. These salt water tracts are very extensive as compared with the areas of gas and oil, occupying hundreds of square miles to one of the former.

7. The height to which the salt water rises in the various portions of the new gas and oil fields, appears to be nearly constant. It reaches an elevation of about 600 feet above tide. If the elevation of the surface is less than 600 feet, as in portions of the Wabash Valley, the salt water flows from the well mouth.

8. The rise of the salt water to the level named is unquestionably artesian in origin. It implies a head of water, established through continuously porous rock, from some more or less distant outcrop. The fact that the outcrops of the Trenton limestone on the shores of Lakes Superior and Huron are dolomitic and consequently porous, and that they are also about 600 feet above tide, suggests this region as the source of the pressure which is shown in the ascent of the salt water in the gas and oil fields. The Trenton limestone is dolomitic as far as it has been followed under the surface of the State of Michigan, both southward from Lake Superior and northward from the Ohio boundary, the facts as to the latter being obtained by the drill.

Rock Pressure.

By the rock-pressure of gas is meant the pressure in a well which is locked in so that no gas can escape. The tubing of the well becomes in this way a part of the reservoir and shares its pressure. This rock pressure varies greatly in different fields and to a less extent in different wells of the same field. It sometimes reaches the enormous figures of 800, 900, or even 1000 lbs. per square inch. Pressures of 400 to 600 pounds to the square inch are not unusual. The phenomena connected

with the escape of gas from a high pressure well are among the most startling in the whole range of mining engineering operations.

There is generally a rough relation between the depth of the well and its rock pressure. The deeper the well, the greater the pressure to be expected, but this relation is by no means constant. Wells of the same depth below the surface may vary widely in rock pressure.

It is the original rock pressure which is needed in these inquiries, and this can be obtained at but one date in the development of a field, and that is at the very opening. Reduction of pressure speedily follows exploitation, and goes forward more or less rapidly as the development proceeds. When a field is locked in, however, after having been opened, there is a tendency to regain the original pressure. The pressure falls through considerable areas at the same time when drainage of gas is going on from any point within them. The rock pressure is a factor of great importance in every gas field. By it, the distance to which the gas can be sent to market, the size of the tubing employed and also the size and strength of the pipe lines are all to be determined.

To what is this rock pressure due? Three answers have been proposed, viz: (1) it is due to the weight of the rock that overlies the reservoir; (2) it is due to the expansive nature of the gas itself; (3) it is due to the pressure of the salt water column which holds joint occupation with it of the porous rock. The facts derived from the new fields demonstrate the truth of the last answer, so far at least as Trenton limestone gas is concerned.

A column of salt water, one square inch in section, one foot in height, and having a specific gravity of 1.1 weighs (and will consequently exert a pressure of) about .476 pounds avoirdupois.

Knowing as we do the height to which the salt water rises in the Ohio and Indiana gas fields, when the porous rock containing it is reached by the drill, viz: 600 feet above tide, we find in this figure an element that we can employ in every subdivision of the field. If the gas is found at sea-level, it will have upon it a weight of $600 \times .476$ lbs. In other words, its rock pressure should be 286 lbs. If the gas is found *above* sea-level, its rock pressure should be reduced in proportion to the reduction of the water column; if found *below* sea-level, its pressure should be correspondingly increased.

The facts derived from the development of the new fields furnish data by which the validity of the explanation above given can be tested.

At Muncie, Indiana, the gas was found in the first wells at

very nearly sea-level. At Marion, Indiana, in well No. 3, the gas was struck at 78 feet below tide. In the Dwyer Well, St. Henry's, Ohio, it was found 200 feet below tide; at Findlay, in the Pioneer Well, at 336 feet below; at the Godsend Well, Wood County, at 395 feet below; at Upper Sandusky, in City Well, No. 1, at 478 feet below; and in the Loomis Well of Tiffin, at 747 feet below tide. The rock pressures, therefore, of these several wells should be found by multiplying the number representing in feet the entire length of the water column by which the gas is compressed in each well by .476 lbs. The lengths of the effective columns in the several wells above named are as follows: 600, 678, 800, 936, 1078 and 1347 feet. The results of the calculations on the basis above indicated, are shown in the following table, in which also other data as to the wells, including their first recorded pressures are given.

Location of wells.	Depth to Trenton limestone.	Relation of gas rock to sea-level.	First recorded pressure.	Calculated pressure on basis indicated above.	Remarks.
1 Muncie, Ind ,	950 ft.	at sea-level	280 to 290 lbs.	286 lbs. = 600 × .476 lbs.	Figures as to wells are approximate.
2 Marion, Ind., Well, No. 3,	870 ft.	78 ft. below	323 lbs.	323 lbs. = 678 × .476 lbs.	
3 St. Henry's, O., Dwyer Well,	1156 ft.	200 ft. bel'w	375 lbs.	381 lbs. = 800 × .476 lbs.	Pressure first noted several months after completion of well.
4 Findlay, O., Pioneer Well,	1096 ft.	336 ft. bel'w	450 lbs.	445 lbs. = 936 × .476 lbs.	Pressure reported by driller. perhaps given in round numbers.
5 Wood Co., O., Godsend Well,	1136 ft.	395 ft. bel'w	465 lbs.	474 lbs. = 995 × .476 lbs.	Pressure not noted at opening of field.
6 Upper Sandusky, City Well, No. 1,	1278 ft.	478 ft. bel'w	515 lbs.	513 lbs. = 1078 × .476 lbs.	Pressure reported by gas trustees.
7 Tiffin, O., Loomis Well,	1455 ft.	747 ft. bel'w	600 lbs. +	641 lbs. = 1347 × .476 lbs.	Gauge read only to 600 lbs.: a considerable excess indicated by it.

The results shown in the preceding table are strictly representative, and no facts from the new fields are known to the writer that militate against the conclusion which these calculations oblige us to adopt, viz: that *the rock pressure of the gas of the Trenton limestone is due to the pressure of a water column under which it is held in the arches of the rocks.* While this explanation of the rock pressure of gas is here applied only to the new fields of Ohio and Indiana, it seems probable that it is applicable to all gas fields.

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