The difficulty of explaining the Third sand pools of these quadrangles by the anticlinal theory, is made greater by the fact that the data in hand indicate that the Third sand is comparatively free from salt water throughout the entire area, except in the vicinity of Elk City and eastward to the Clarion and Miola pools, in Clarion County, where salt water is pumped with the oil. The salt water area in this region is in the structurally highest portion of the producing belt of the Third sand, a fact that is in direct opposition to the idea of accumulation by difference in gravity of oil, gas, and salt water.

In these old fields it is now impossible to collect sufficient facts to get a clear understanding of the minor geologic details under which the oil and gas pools occur. These facts are of the utmost importance in explaining the positions of these pools. One fact may be pointed out, however, to which some significance is attached: there is in this field (as in almost every other field so far examined in the Appalachian region) at some height above the oil sand a bed saturated with water which is usually saline. It is believed by the writer that this persistent and almost universal feature of the stratigraphy of producing territory bears a greater part in the accumulation of oil and gas than geologists have heretofore thought.

The fundamental principle of the anticlinal theory, namely, the accumulation of pools through difference in gravity of oil, gas, and salt water, would not seem to be applicable to these pools, even if they showed a marked structural arrangement, because, with the very slight dip of the rocks, averaging less than 75 feet to the mile, the maximum pressure that could have been exerted by a globule of oil toward movement along the bedding planes could not have been more than about five-thousandths of the weight of the globule. The resistance to this force offered by the water-logged pores of the sandstone was doubtless amply adequate to prevent the accumulation of these great pools under pressure ranging from 100 to probably 1000 pounds per square inch.

The force exerted by a body of water slowly soaking downward through drier, close-grained shale and sandstone from a water-bearing stratum above is entirely adequate to push along ahead of it a considerable portion of the oil and gas scattered throughout the shale mass and from which the oil and gas of the pools have doubtless been derived. This water would travel by a combination of hydraulic and capillary pressure. Such a body of water might in this case have come as easily from below as from above, provided a water-bearing bed is available in that direction. In either case the body of water would have continued to move out into the drier rocks from the water-bearing bed until the supply became exhausted, or until the hydraulic (not hydrostatic) element of pressure became reduced to zero by friction and the capillary pressure, also exhausted by the advancing line of saturation, encountering open porous beds where the force exerted by capillarity would be greatly reduced. Under such conditions the water would have a tendency to move the oil vertically from the close-grained shales into the more porous patches of any sandstone which might happen to be favorably situated at or near the zone where both the hydraulic and capillary pressures became exhausted. In areas where the hydraulic pressure of the water is not entirely exhausted by friction more or less water will appear in the wells with the oil.

By following out this suggestion a satisfactory explanation can be had of many of the variable structural relations manifest in the oil and gas fields of these quadrangles, and with a full knowledge of underground water conditions in these quadrangles it is believed that the whole scheme of accumulation would be so clear as to be unquestionable. If it is assumed that the oil pools have been accumulated in some such manner as suggested above, it seems probable that the water movement was downward through the Cuyahoga formation and that the original source of the water was largely from above, probably from either the First sand or the Burgoon sandstone. It is assumed that these sandstones derived their supply from distant intakes where they are exposed at the surface and that the invasion occurred at some definite, short, clearly marked geologic time. In areas where oil pools were formed the water from this sandstone is assumed to have slowly soaked downward through shale by capillarity augmented by hydraulic (not hydrostatic) pressure and to have gathered in front of it a zone of oil and gas. Slow downward movement of the water and oil zones would continue, however, until the oil zone should come to an open porous bed just beyond the point where the water could no longer exert hydraulic pressure because of loss of head by leakage and friction. At the upper edge of this porous bed the capillary pressure of the overlying water would also cease to exert its full force because of the increased size of the pore spaces of the rock, and an equilibrium would be established between the remaining capillary water pressure and the resistance offered by the oil to movement. The same result would be reached if two bodies of capillary water should meet on opposite sides of a porous stratum.

Probably most oil and gas pools were formed by the movement of two or more bodies of water in different directions. The first stage was the transfer of the oil and gas from the shale to a more porous sandstone above or below by water invading the shale in more or less vertical direction, as stated above. The second stage, from an economic viewpoint far more complicated, was the subsequent invasion by water of the porous bed into which oil and gas had been driven. In this stage the water must have traveled along the bedding planes by hydraulic pressure, thus still further concentrating the accumulations of oil and gas into pools. The source of the water may have been the same in both stages, or it may have come from entirely different sources during each stage. If from the same source, the water which invaded the sandstone parallel to its bedding plane was derived from the water-bearing bed above or below, at distant points through fissures, faults, etc., and, having encountered less resistance, retained sufficient hydraulic pressure to have caused it to move horizontally along the porous sandstone. The points where water was thus derived may have been few or many, and the radial movement from these points of intake may have been, therefore, relatively great or very small. In all cases where oil and gas pools were formed, the vertical invasion of the first stage must have preceded the horizontal invasion of the second stage, and the accumulating effect of the second was supplementary to that of the first.

The horizontal movement of water by hydraulic pressure through the oil-bearing sandstone from the point or points of invasion could not have been uniform in all directions, because of variations in porosity of the sandstone and of structural features. Hence, each puddle retained a ragged margin at all stages of this invasion. The oil and gas forced ahead of the water around the margin of each puddle traveled by the hydraulic pressure of the water behind, but their resistance to movement was largely capillary in nature and this resistance must have increased in proportion to the increase in size of the oil and gas body, while the hydraulic pressure of the water decreased with distance from the source of supply. In such a movement the gas, being less dense and offering less resistance to movement than the oil, would collect in advance of it and farther away from the water.

Such a movement of water would offer opportunity for the formation of oil and gas pools under many different local conditions. The simplest of these would be of pools formed along the line of contact between two bodies of water moving in opposite directions from different points of intake in the porous sandstone. Along such a line the pools of commercial value would occur only at places where the sandstone was sufficiently porous to furnish a flow into the wells under the closed pressure of that particular pool. Pools would also be likely to form along the sides or crests of anticlines, especially in domes where the base of the fold in the oil-bearing sandstone was first surrounded by the invading water which subsequently encroached upon it from all sides, pinching the oil and gas in the top. These examples, which are the simplest types of pools, are cited to illustrate the principles involved. Other factors equally effective in controlling the position of pools would be the pinching out of the sandstone member, the encountering of barriers of much finer sandstone occupied by capillary water derived from the associated shale from which the supply of oil was originally derived, or the formation of dams in the sandstone by the foremost portion of the moving body of oil itself occupying through capillarity fine-grained areas to such a distance as to offer a relatively great resistance to the water at the point of contact in the porous portion of the bed. In all cases the water pressure must be considered to have been hydraulic and not hydrostatic. In areas where no water is now found in the productive sand around the margin of a pool, the water at the edge of the pool may have subsequently lost all hydraulic pressure through reduction of the supply of water or the decrease in head due to structural changes. In either case the capillary resistance offered by the water to backward movement would have been too great to change materially the position of a pool after it was once formed. The great closed pressures of pools probably are due to chemical changes in the oil body after it was collected, thereby increasing the volume of gas in the pool.

A thorough discussion of this theory and of others relative to oil and gas accumulation is not germane to the subject in hand, since it would involve regional studies that are not at present sufficiently complete to admit of positive deductions being made. It may be shown, however, that the idea of oil and gas accumulation by moving water under a combination of hydraulic and capillary pressure is easily applicable to all types of oil and gas pools, but physical facts to substantiate it can not be readily secured in old producing areas similar to those of the Foxburg and Clarion quadrangles.

CLAY AND SHALE.

Clay and shale are exploited in both the Foxburg and the Clarion quadrangles. The clay includes both the flint and plastic varieties, but neither is used extensively.

SHALE.

The only shale that is being developed commercially at present is the one below the horizon of the Clarion coal. The Canton Tile & Hollow Brick Co. has a pit on this shale about three-quarters of a mile west of New Bethlehem and uses it in connection with the underlying clay in the manufacture of hollow building blocks and drain tile. A section of the pit is as follows:

Section of pit of Canton Tile & Hollow Brick Co.

	Ft.	in.
Shale, olive, fissile, iron stone	3	
Carbonaceous layer (Clarion coal ?)		4
Sandstone, argillaceous		10
Shale, dark drab	18	
Clay, dark, soft	5	
Clay, drab, hard, sandy	5	
Shale, olive, sandy	10	
Sandstone		

Other deposits of shale of possible commercial value occur above the Lower Kittanning coal. This shale is usually fine-textured, and exposures indicate that it averages between 30 and 50 feet thick. Good sections occurring on or near railroads are exposed at the railroad crossing between Fairmount City and Hawthorn, in the hill 1 mile south of Sligo, and in the hill 1 mile south of Strattonville.

CLAY.

Clay in Mercer shale member.—In some parts of western Pennsylvania the Mercer shale member contains valuable clay which is presumably equivalent to the Mount Savage clay of Maryland, but in the Foxburg and Clarion quadrangles there is very little clay in this member. There is, however, much clay shale, and some dark-gray clay, none of which has been worked. The member outcrops along the gorges of Clarion and Allegheny rivers and the larger tributary streams. In the northeastern part of the area it is very thin.

There is no good exposure of flint clay in the Mercer member in the Foxburg and Clarion quadrangles, but south of this area, at Climax and St. Charles, flint clay from the Mercer is used in making high-grade fire brick. At one point within the area, namely, on the west side of Leatherwood Run, about 1 mile north of St. Charles, fragments of flint clay which are probably from the Mercer have been found in the field. Several prospect holes have been sunk here, however, without finding the source of the fragments.

Brookville clay.—The Brookville coal is underlain by a bed of clay 1 to 10 feet thick, and the clay is present in many places where the coal is absent. It is generally very sandy and of little value.

Clarion clay.—One of the most conspicuous clay beds in the western part of the area is found below the Lower Clarion coal. It is plastic and generally white in weathered outcrop. The thickness ranges between 3 and 10 feet. In some districts the Upper Clarion coal is also underlain by clay. A section on the run near the schoolhouse about 2 miles southwest of Piney shows 5 feet or more of clay, below each of the Clarion coals. In the vicinity of New Bethlehem this clay is being used, as already stated, with the overlying shale in the manufacture of building blocks and tile by the Canton Tile & Hollow Brick Co. Clay found below the Lower Clarion coal in one of the mines at Sligo is used as a bond in the manufacture of fire brick.

Kittanning clays.—In some localities there are at least four Kittanning coals, each underlain by clay beds. The upper clays are, so far as known, unimportant. The plastic clay below the Lower Kittanning coal is as yet undeveloped, but road crops and mine sections throughout the area indicate that except in the northwestern part, it is persistently present. Only a partial thickness of the clay is anywhere seen, but the exposures are suggestive of considerable deposits. Among the best road exposures is one $1\frac{1}{4}$ miles east of Jack schoolhouse, and about 4 miles northwest of New Bethlehem, where 3 feet of reddish stained clay outcrops, and another 1 mile east of Frampton, where 8 feet of light-drab clay is exposed. At Huey a drift exposes $7\frac{1}{2}$ feet of clay, with both top and bottom concealed. The thickness of the clay here indicates that possibly equally thick deposits are accessible along the Sligo branch of the Pennsylvania Railroad, wherever the numerous mines show that the clay occurs above drainage level.

The only plastic clay in present use from the Kittanning beds comes from the Middle Kittanning. This clay is used at Hawthorn in the manufacture of stoneware, and the supply is obtained from a stripping just north of the town. The clay lies under 4 to 10 feet of cover, and ranges between 4 and 6 feet in thickness. The upper portion of the bed is soft, quite free from sand, and has a chalky appearance, due to weathering, while the lower portion is rather hard and sandy, and greenish in color. The Middle Kittanning clay was formerly stripped on Town Run, opposite the opening of the No. 2 mine of the Alcola Coal Co. This was reported to be an excellent pottery clay.

Flint clay occurs below the Lower Kittanning coal in a belt that extends from just west of the Foxburg-Clarion boundary to the north border of the area. This belt has a width of