Ohio Geology

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THE DAWN OF A NEW OIL BOOM FOR NORTHWESTERN OHIO? MERIDIAN OIL BEGINS A PILOT WATERFLOOD PROJECT IN ALLEN COUNTY

by

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and

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Meridian Oil, Inc., of Houston, Texas, started a pilot waterflood program in the Trenton Limestone last summer near the city of Lima (Allen County) in an attempt to recover oil left in the rock during Ohio's oil boom a century ago. If this pilot project proves successful, vast areas of northwestern Ohio and eastern Indiana may be open to similar secondary recovery attempts from this once-prolific reservoir rock.

The Lima-Indiana oil and gas trend, which was extensively drilled in the late 1800's and early 1900's, extends in a broad curve for 185 miles from Toledo, Ohio, southwestward to Indianapolis, Indiana. The Ohio portion of the field is 120 miles long and ranges from less than 1 mile wide to as much as 20 miles wide. More than 60 individual fields have been named along the trend in Ohio. The principal reservoir rock in all of these fields is the Trenton Limestone of Ordovician age.

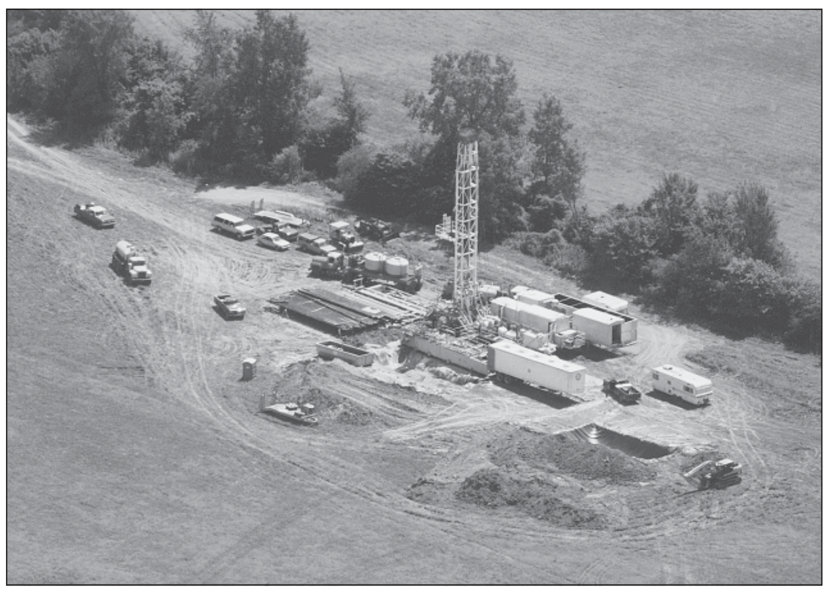
The Trenton oil and gas boom began in 1884 when a significant quantity of gas was discovered in a well just east of Findlay (Hancock County). This discovery, and the increasing amount of production from subsequent wells around Findlay, sent a shock wave of excitement through northwestern Ohio communities. They viewed the gas as a way to attract and fuel industries in their towns.

In early 1885, Benjamin Faurot, a Lima civic leader and business man, traveled to Findlay to see the gas wells. He returned home convinced that he could find gas around Lima also. Faurot gathered a group of investors to drill the first well on his property. On May 9, 1885, the drill reached the Trenton Limestone but there was no gas, only a show of oil. Before abandoning the attempt, Faurot decided to shoot the well with explosives. To the amazement of the crowd that had gathered, the well began flowing 200 barrels of oil per day.

This oil well was the first in northwestern Ohio and marked the opening of the Lima field. Several local prospecting companies quickly formed and derricks sprang up all over the city of Lima. Benjamin Faurot and a group of investors started the Trenton Rock Oil Company. By 1886 this one company alone had drilled more than 250 wells in an area from Lima through St. Marys (Auglaize County) and into Indiana.

The wells around Lima were good, steady producers, consistently producing about 25 to 200 barrels of oil per day per well. However, in late 1886 and early 1887 they were overshadowed by spectacular Trenton wells drilled in Wood and Hancock Counties; These wells produced from 500 to 10,000 barrels per day.

Such volumes of oil overwhelmed an infant industry, and prices plummeted from 40 cents per barrel to 15 cents. The producers around Lima couldn't compete with the larger producers at that rate. Therefore, 14 local oil producers formed a combine called the Ohio Oil Company, which was the predecessor of the modern Marathon Oil Company. They took their oil off the market until prices again reached 40 cents per barrel. The Ohio Oil Company was eventually absorbed by the Standard Oil Company, which was aggressively trying to take control of northwestern Ohio oil production and marketing. The government broke the Standard "monopoly" into 32 separate companies in 1911, thus returning the Ohio Oil Company to independent status.



Aerial photograph of rotary drilling rig at Meridian Oil's pilot waterflood project in Allen County. Photo courtesy of the Lima News, used by permission.

The Lima-Indiana trend was the first true giant oil and gas field discovered in North America. Production from the Ohio portion of the Lima-Indiana trend rose rapidly from negligible quantities in 1885 to more than 1 million barrels of

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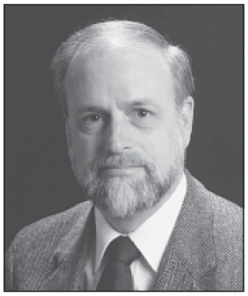

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From The State Geologist...

Thomas M. Berg

SEEING THE NATURE OF THINGS BENEATH OUR FEET

In his presidential address given before the American Society of Naturalists in 1885, G. K. Gilbert reflected on the education of scientists:

> The great investigator is primarily and preëminently the man who is rich in hypotheses . . . . He is to observe phenomena, he is to frame and test hypotheses. As a matter of course, in order to learn to do these things he must do them. Sooner or later he must be sent directly to nature, out of doors or in the laboratory, and must in her presence train his faculties by practice.

Grove Karl Gilbert (1843-1918) was one of the most eminent individuals in the history of American geological science. He gained much of his experience while employed by the Ohio Geological Survey under the direction of J. S. Newberry, second State Geologist of Ohio. Gilbert is probably best known for deciphering the geomorphic history of ancestral Lake Bonneville in Utah while in charge of the U.S. Geological Survey's Salt Lake City office from 1879 to 1881. As a geoscientist, he understood the critical need to get into the field and observe nature, developing hypotheses as successive approximations until a "best fit" was arrived at. Gilbert clearly perceived the natural world as a balanced and ordered system which could be analyzed mathematically. But nothing could be analyzed unless it was thoroughly examined in the field within its own environment.

As new geologists are being trained today, there is a disturbing trend that has been developing for some time. It is in striking contrast to G. K. Gilbert's call for training and experience in observing natural systems. At many colleges and universities across the nation, the art and science of conducting field work, making field observations, synthesizing and interpreting field data, and constructing geologic maps have been abandoned or severely minimized. At the same time, we are witnessing an explosion of computer technologies in the geosciences. Training geology students to use computers is extremely important, but it should take place <u>in addition to and as a supporting technology</u> in the education of geologists in the "up front and personal" observation of geological phenomena. All of the computer technology in the world will be of little help to a geologist who has an inadequate understanding of the natural order that pervades Earth systems.

In a recent editorial in *The Professional Geologist* (American Institute of Professional Geologists, April 1995), Gerald L. Fletcher expresses a very similar and serious concern:

> Exploration for petroleum has taken a nasty turn away from fundamentals of geology into the glare of the headlights of 3-D seismic. In many companies it appears there is a feeling that 3-D seismic will tell all. The concept is that the more data you put into a work station, the more useful it is . . . .
>
> Our geophysical friends are imaging subsurface phenomena in great detail and displaying this detail in 3-dimensional models which were unheard of a short time ago. Somebody has to correctly interpret what they mean . . . . The more training, experience and imagination a person has, the more valuable he or she will be and the more he or she will contribute to the exploration effort . . . . Where else but on the outcrop can a young geologist learn what geologic phenomena actually look like in three dimensions? . . . It occurs to me that more than ever before, a solid, extensive training gained from study of outcrop geology is the only way geologists can be adequately equipped to handle the immense volume of 3-dimensional subsurface information which is now being generated.

Hear! Hear! How right you are Mr. Fletcher! And how right was G. K. Gilbert. We have enormous subsurface exploratory capabilities today, and as can be seen in this issue of *Ohio Geology*, we have important potential oil and gas reserves that need to be explored. But what good will the high-tech geophysical capability be if the geologist doing the interpretation has no field and outcrop training and experience? Let's hope our geology departments in the United States will reemphasize field work, careful observation of real outcrop geology, and the compilation and interpretation of geologic maps so that we will be able to see the true nature of things beneath our feet!

General Interest Publications List

Inserted in this issue of *Ohio Geology* is a list of general interest publications available from the Division of Geological Survey. The list, which serves as a handy order form, notes only a small percentage of geological publications and maps available from the Survey. A comprehensive *List of Publications*, as well as a *List of Educational Resources*, are available at no charge. All three lists have been updated recently.

History of coal mining in Ohio

The Survey has just released Bulletin No. 72, *History of the coal-mining industry in Ohio*, by Survey coal geologist Douglas L. Crowell. This 204-page publication has 186 photographs, nine maps, and 27 line drawings that depict all aspects of Ohio's long and productive coal-mining history. This volume is available for $12.00 plus $2.00 shipping. Ohio residents must add $0.69 sales tax. Please call 614-265-6576 to place credit card orders.

continued from page 1

oil in 1886, and reached its peak in 1896, when more than 20 million barrels were brought out of the ground. Unfortunately, production declined almost as rapidly as it grew; by 1906 annual production had fallen to 10 million barrels, and to less than 1 million barrels in 1934.

Plugging of wells and the abandonment of the trend was hastened by the discovery of the giant fields of Texas in 1901, when the Spindletop well was drilled. This phenomenal well roared onto the scene producing 100,000 barrels of oil per day! Again, the oil market was oversaturated and prices dropped to a low of 3 cents per barrel. Wells in Ohio could no longer remain profitable and companies shut down all but the best producers.

Cumulative production and the total number of wells drilled in the Lima-Indiana trend are difficult to determine because of a lack of records. However, estimated figures are 500 million barrels of oil, 1 trillion cubic feet of gas, and 100,000 wells for the entire trend. The Ohio portion of the trend is thought to have produced roughly 380 million barrels of oil from about 76,000 wells.

Since the early 1900's, many oil and gas operators have discussed the possibility that large amounts of oil were left in place along the Lima-Indiana trend and that this oil was ripe for secondary recovery operations. Such speculation was fueled by the very fast, unsophisticated manner in which these fields were originally produced and the swift, perhaps premature abandonment. Many reasoned that the residual oil saturation left in place would be abnormally high; some theorized that as much as 90 percent of the original oil was still in the ground. Considering the estimated 500 million barrels of oil already produced from this trend, a lot of oil may be left for secondary recovery!

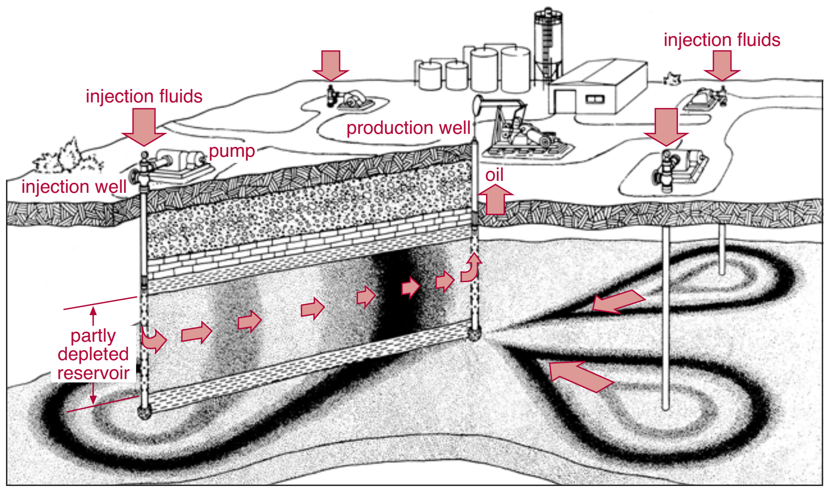
Since the 1950's, a number of companies have actively investigated the possibility of secondary recovery in the old Trenton fields, and at least one attempt using a technique called waterflooding has been tried in Hancock County. Most operators have walked away without drilling a well, scared off by the potential problems caused by numerous unlocated, abandoned, and unplugged wells in the vicinity. The one documented attempt can only be described as a economic failure.

In a typical waterflood project, water is injected into a central well (or wells) at high pressures and volumes. The object is to sweep the remaining oil in the formation in front of the "flood" to surrounding pumping wells. This type of approach probably would not be effective in the old Trenton fields, largely because of the numerous old well bores. The high injection pressure would drive the water (and oil) up any unplugged boreholes, breaking up the flood system.

On March 17, 1994, the ODNR, Division of Oil and Gas received a unique application from Meridian Oil to permit a pilot waterflood of the Trenton Limestone. Meridian is one of the world's leading companies in secondary recovery technology. They proposed to develop this pilot project on 620 acres of mostly farmland in Allen County near Lima. The Division of Oil and Gas requires a review of the area within 1/2 mile radius around such proposed projects. Their investigation of this area disclosed more than 120 historical wells, of which only three have complete records, including plugging reports.

To alleviate any threat to the lowermost underground source of drinking water (USDW) in the area, Meridian's plans call for performing sophisticated electromagnetic surveys in a specified radius around each of their injection-well sites to locate any old, potentially improperly plugged wells. A series of monitor wells will continuously keep track of Trenton fluid levels and ground-water quality.

Meridian will limit the injection pressures on their wells to a maximum of 50 psi (pounds per square inch), well below maximum allowable pressures and those used in most waterflood projects. Such low pressure creates a very slow flood that will not force oil, brine, or injected water to migrate up old, improperly plugged well bores (if any are encountered). Their computer reservoir modeling leads Meridian to believe that this method will be



Diagrammatic cross section of an enhanced-recovery project that uses waterflood technology. In a typical waterflood project, water is injected into the partly depleted reservoir rock. The injected water fills the pore spaces of the rock and pushes the remaining oil in the reservoir toward the producing well. Modified from U.S. Department of Energy Report BETC-79/4 (1980, p. 23).

an effective and environmentally safe way to extract untapped oil reserves from this almost-forgotten area of Trenton production.

To fully develop the 620-acre pilot tract as one consolidated operation, Meridian applied to the Division of Oil and Gas for a unitization order. Unitization involves the consolidation of mineral-lease interests covering a common source of supply. The primary function of unit operations is to maximize production by efficiently draining the reservoir using the best available technology. Unitization is very common in other states that have more active secondary recovery operations, but it had never been used successfully in Ohio. After careful consideration, many meetings with Meridian, and a public hearing on the unitization order, the Division of Oil and Gas issued its first unitization order and the requested drilling permits in July 1994.

Drilling began in August 1994. A rotary drilling rig drilled to the top of the Trenton Limestone (approximately 1,300 feet deep). At this point a cable-tool rig was set up to drill through the Trenton. The cable-tool rig was used to lessen damage to the formation, obtain more effective depth control, and for better sample recovery through the pay zone. Surface casing was set to a depth of approximately 450 feet (through the lowermost USDW) and cemented to the surface. Seven-inch diameter casing was set at the top of the Trenton and cemented to a minimum of 300 feet above the injection zone. The injection wells were completed by running 2 3/8-inch tubing to approximately 50 feet above the injection zone.

Meridian has completed eight injection wells, eight production wells, two deep (Trenton) monitor wells, and two shallow ground-water-monitoring wells on this pilot tract. All of these wells are tied to a central facility, where the oil is gathered and the injection water treated and pumped. Each well has a computerized monitoring system that sends data to the central facility so that each well, tank, and pump on the project can be monitored 24 hours a day. To tie all of their operation together, Meridian has installed approximately 55,000 feet of pipe, 33,000 feet of cable, and over 5 miles of roads on this 620-acre site!

It will be a number of months before Meridian begins to see results from this project to indicate their level of success. If their modeling is correct, over 500,000 barrels of oil may be produced from this pilot site. Meanwhile, they have started a similar pilot project in an old Trenton field in eastern Indiana. If these projects are successful, vast areas of northwestern Ohio and eastern Indiana could be reopened for secondary recovery operations and significant oil production could be seen again from this sleeping giant oil reservoir.

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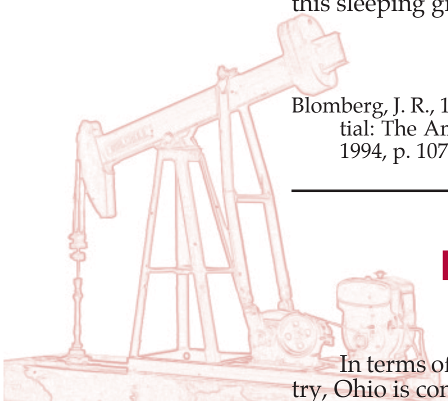


ENHANCED-RECOVERY PROJECTS IN OHIO

by Mark E. Wolfe and Lawrence H. Wickstrom

In terms of the international petroleum industry, Ohio is considered part of a mature hydrocarbon basin; that is, most of the petroleum reservoirs are thought to have been discovered and most of the primary production has been recovered from those reservoirs. Although much exploration continues today in Ohio, especially in the deeper Ordovician- and Cambrian-age strata, the mature status does apply for most of the shallow reservoirs in our state. Most of the best production areas from the shallower horizons have been defined and developed. Primary production in many of the larger "Clinton" and Berea Sandstone fields developed in the 1960's through the early 1980's is now in decline.

A number of companies are engaged in or considering secondary oil recovery in Ohio's declining or abandoned fields using enhanced-recovery technologies. Some feel that Ohio is past due for a concerted effort to increase production through enhanced-recovery projects (EPR's). Ohio's current production from ERP's accounts for less than 5 percent of the state's total yearly oil production, whereas in some surrounding states, secondary recovery accounts for approximately 25 to 50 percent of total production.

Enhanced-recovery techniques have been developing almost as long as the oil industry has been in existence. Ohio was an early innovator in secondary recovery technologies. Depending upon the process used, an operator may expect to recover from $^1/_2$ to more than 1 barrel of secondary oil for every barrel of primary oil produced. Ohio has produced more than 1 billion barrels of oil since 1860, so there is no lack of ERP prospects to be examined.

One of the earliest attempts at secondary recovery in Ohio was conducted in 1911 by the Cumberland Oil Company and I. L. Dunn in the Chesterhill field in Morgan County. The Pennsylvanian "Cow Run" sand, at a depth of 400 feet, was repressurized using compressed air. By 1917, about 4,000 wells were affected by this process, termed the Smith-Dunn or Marietta compressed-air process. It is estimated that 80 percent of the projects were successful, and an average increase of $3^1/_2$ times the rate of production was realized from the time repressuring began. The largest repressuring project was in the Sistersville field in Monroe County, where gas was injected in 19 injection wells beginning in 1933. The daily production rate of 374 wells was slowly increased from 124 barrels of oil per day to a peak of 337 barrels of oil per day in 1939, when a slow decline began.

Waterflood technology got its start in the giant Bradford field of northwestern Pennsylvania in the 1930's. As soon as the Ohio legislature legalized waterflooding of oil sands in 1939, waterflooding of the shallow Mississippian Berea Sandstone was attempted in the Chatham field in Medina County. By 1949, 325 injection wells and 392 producing wells were producing 650 barrels of oil per day. Estimated total flood production from the field was 2,250,000 barrels of oil. Active waterflooding continued into the 1960's, and it is conservatively estimated that in excess of 5,000,000 barrels of oil have been recovered from the Chatham field.

As of early 1995, 43 enhanced-recovery projects are active in Ohio. Approximately 700,000 barrels of water were injected in 1994. Some of the more significant enhanced-recovery activities include:

◊ The Quaker State Corporation Berea Sandstone (Mississippian) waterflood in Ashland County. This project was initiated in 1974 with 123 injection wells and 116 production wells; 4,109,845 barrels of water have been injected since 1982. Estimated cumulative oil production exceeds 2,000,000 barrels.

◊ The Mitchell Energy Corporation Pennsylvanian sandstone waterflood in Lawrence County. Since 1991, 375,000 barrels of water have been injected in 17 wells. By 1993, when the full flood effects were realized, 49,349 barrels of oil per year had been produced from 25 wells, representing 2.7 times the production anticipated by the normal field-decline curve.

◊ The Baldwin & Baldwin (formerly owned by Sun Oil Company) waterflood of the "Krysik" sandstone (Cambrian) in Erie County. Primary production was more than 600,000 barrels when waterflooding began in 1974; 2,178,435 barrels of water have been injected since 1982. Estimated total cumulative production is 1,500,000 barrels of oil.

◊ The Oxford Oil Company (formerly Preston Oil Company) "Clinton" sandstone (Silurian) waterflood in Coshocton County. This project was initiated in 1965. Yearly production was 680 barrels of oil in 1965 and increased to 4,848 barrels by 1968. Cumulative production by 1971 from seven wells was 370,000 barrels. Production continued through 1994.

1994 OHIO OIL AND GAS DEVELOPMENTS

by Michael P. McCormac
ODNR, Division of Oil & Gas

Permitting projections throughout 1994 indicated that drilling activity would be greater than in 1993 and that more wells would be drilled to the Rose Run sandstone than the "Clinton" sandstone. However, rather surprisingly, there was not an increase in the number of wells drilled, and, although a record number of Rose Run wells were drilled, the "Clinton" still remained the most actively drilled zone. The overall decline in drilling can be attributed partially to lower prices for oil and gas in 1994. Another contributing factor was that many operators obtained three or four Rose Run permits in an exploratory area but, after the first well was dry, did not drill the other permits.

Permitting activity increased in 1994, ending the decline that began in 1985. The Division of Oil & Gas issued 2,318 permits in 1994, an increase of 8.6 percent (183) from 1993. This total includes permits issued to convert, deepen, drill, plug back, plug and abandon, reissue, and reopen. Drilling and plugging permits accounted for most of this increase.

In 1994, the Division issued 996 permits to drill for oil and gas, a 10.2 percent increase from 1993. These permits included 885 new permits and 111 reissue permits. Deep well permits increased 11.3 percent (50) and accounted for 50 percent of all new well permits. Deep well permits are permits issued to formations below the Knox unconformity, such as the Beekmantown, Rose Run, Trempealeau, and Mt. Simon.

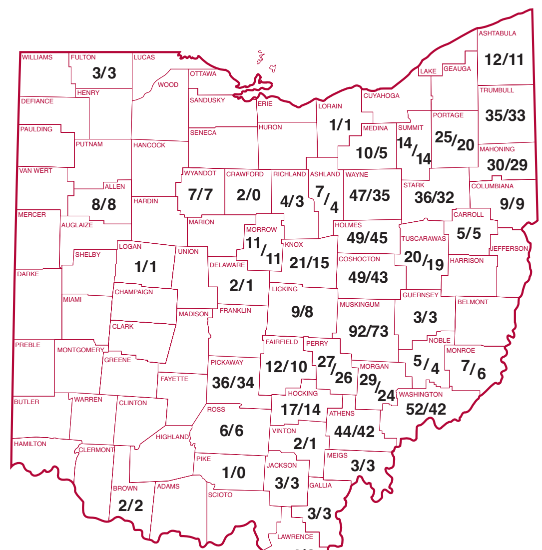
An estimated 765 oil and gas wells were drilled during 1994, a decrease of 58 wells (7 percent). For the third consecutive year, and only the eighth time since 1888, the number of wells drilled fell below the 1,000-well mark. The 1994 total is the lowest since 1935, when 736 wells were drilled. Wells were drilled in 44 of Ohio's 88 counties, a decrease of two counties from 1993.

The majority of wells (626; 95 percent) completed in 1994 were drilled by rotary tools. Cable-tool rigs drilled 34 wells in 12 counties. Cable-tool depths ranged from 253 to 4,080 feet. The average depth per well drilled by cable tool was 2,093 feet; rotary-drilled wells averaged 4,815 feet.

Ohio now has 64,473 active wells and 3,904 well owners. The number of owners drilling wells in 1994 declined by 28. Well-completion records show that 153 owners drilled wells; 91 percent (139) of these owners drilled 10 or fewer wells, including 69 owners who drilled only one well. These 139 owners accounted for 59 percent of the wells drilled (388). The highest number of wells drilled by a single owner was 50.

Ohio oil and gas owners/operators submitted 660 well completions, representing 86.3 percent of the wells drilled in 1994. These reports showed that 510 wells were productive and 150 were dry holes, for a 77.3 percent completion rate. Average well depth was 4,675 feet, a decrease of 52 feet per well from 1993. Total depth ranged from 253 feet in the Berea Sandstone (Lorain County) to 7,775 feet in the Rose Run sandstone (Tuscarawas County). Twenty-five additional reports were received for other types of drilling operations.

Approximately 23 percent (149) of all wells completed were classified as exploratory wells; 63 were completed and 86 were dry holes, representing a 42.3 percent success rate, an increase of 2 percent from 1993. Wells drilled below the Knox unconformity accounted for 93 percent (138) of all exploratory drilling; 53 of these wells (38 percent) were productive. The Cambrian-Ordovician Rose Run accounted for 99 of these wells; 35 were productive. The Cambrian Trempealeau had 24 exploratory tests, of which eight were productive. All 10 exploratory wells drilled to the Ordovician Beekmantown were productive.



New wells drilled for oil and gas in Ohio in 1994, by county.

1994 DRILLING OPERATIONS BY TYPE OF WELL

Type of hole	*Drilled*	*Converted*	*Total footage*
Productive wells	510		2,334,376
Dry holes	150		751,112
Reopened wells	3		0
Lost holes	4		7,797
Gas storage wells	5	0	14,815
Conventional brine-injection wells	0	1	0
Enhanced-recovery wells	10	2	13,965
Solution-mining wells	3	0	8,708
TOTAL	685	3	3,130,773

> "Ohio's total reported crude oil production in 1994 was 8,757,872 barrels, an increase of 475,849 barrels (5.7 percent) from 1993."

COMPLETION ZONES

Completion zones ranged from several shallow Pennsylvanian sandstones to the Precambrian basement rock. Washington County again had the most diverse drilling activity. Wells in this county were drilled to five different geologic zones ranging from the Pennsylvanian Maxton sandstone to the Silurian "Clinton" sandstone. Generally, the number of wells drilled to reservoirs of Pennsylvanian to Silurian age declined, and those drilled to producing zones of Ordovician to Precambrian age increased.

"Clinton" sandstone

Despite a decline of 60 wells, the Silurian "Clinton" sandstone has remained the most actively drilled zone since 1965. Forty-one percent (269) of the total wells were completed in this zone, the lowest number of "Clinton" sandstone wells completed since at least 1950 and most likely since the early 1930's. "Clinton" sandstone wells had a 98.5 percent completion rate and averaged 4,732 feet in depth, an increase of 87 feet per well from 1993. "Clinton" wells were drilled in 24 counties. The most actively drilled "Clinton" sandstone counties were: Trumbull (33), Mahoning (29), Washington (28), Athens (27), and Stark (25). Overall, "Clinton" drilling declined in 17 counties. The greatest decline took place in Stark County (22 wells) and the greatest increase took place in Athens County (20 wells).

Rose Run sandstone

Drilling to the Cambrian-Ordovician Rose Run sandstone broke the 200-well mark for the second consecutive year. By the reporting deadline, 229 completion reports had been received; that number is expected to increase to 272. The productive rate declined for the first time in five years from a high of 65 percent in 1993 to 55 percent. It is expected that the 1994 productive rate will be adjusted to 60 percent when all the Rose Run well completions are received. Rose Run wells were drilled in 16 counties by 59 operators. The average depth per well was 5,375 feet, a decline of 693 feet per well. This decline resulted from a shift in drilling from northern Ohio counties to southern and central Ohio counties, where the Rose Run sandstone is shallower. Muskingum County was again the most active county (46 wells), followed by Holmes (35), Pickaway (31), Coshocton (26), and Perry (21) Counties. Fourteen townships had first-time producing Rose Run wells.

Although 83 percent of Ohio's estimated 1,447 Rose Run wells have been drilled since 1984, the significant upturn in activity began in 1987. Since 1987, 1,140 Rose Run wells have been drilled in 24 counties. In 1994, only 15 percent of Rose Run dry holes were plugged back to the "Clinton" sandstone, indicating that most Rose Run prospects are being drilled without the "Clinton" as a back up.

Trempealeau dolomite

Wells completed to the Cambrian Trempealeau dolomite decreased by 29 to 58 in 1994. Wayne County (20 wells) was the most active county. Trempealeau wells were drilled in 15 counties, a decrease of one from 1993. As in 1993, 43 percent of all Trempealeau wells were completed as productive. The average depth per well was 4,721 feet, an increase of 16 feet per well from 1993.

Beekmantown dolomite

Wells completed to the Ordovician Beekmantown dolomite increased from 5 to 21 in 1994. Tuscarawas County led with 9 wells, followed by Muskingum (6), Hocking (5), and Vinton (1) Counties. Twenty of these wells were productive. The average depth per well was 6,337 feet. It is anticipated that the number of wells drilled to this zone will continue to increase in 1995.

Berea Sandstone

The Mississippian Berea Sandstone ranked fifth among producing formations; 20 wells were completed in 10 counties, a significant decline of 37 wells from 1993. Licking County had the most Berea Sandstone wells (4). The average depth increased by 278 feet per well to 1,034 feet.

Devonian shale

Drilling interest in the Devonian Ohio Shale declined to 12 wells in 1994, compared to 35 in 1993. Monroe County led Ohio Shale drilling with 6 wells. The average depth per well was 1,982 feet, a decrease of 653 feet per well.

TEN MOST ACTIVE COUNTIES

Muskingum County led the 1994 top-10 list with 92 new wells drilled, a gain of 23 wells from 1993. For the fifth consecutive year the first-ranked county had fewer than 100 wells drilled. Drilling in Washington County increased by 5 wells, moving it into second place.

Top-10 counties were distributed throughout eastern Ohio in areas where the "Clinton" sandstone or the Rose Run sandstone is being drilled. Eight of 10 counties retained top-10 status from 1993. Perry County and Portage County had declines of 10 wells and 25 wells, respectively, and dropped from the 1994 list. Athens County had an increase of 20 wells and was in the top 10 for the first time since 1966. Pickaway County joined the top 10 for the first time ever.

TEN MOST ACTIVE COUNTIES

1994 rank	*County*	*1993 rank*	*Wells drilled*	*Permits issued*	*Footage drilled*
1	Muskingum	1	92	118	393,988
2	Washington	6	52	79	192,509
3	Coshocton	2	49	62	230,470
3	Holmes	3	49	58	256,253
5	Wayne	8	47	57	197,217
6	Athens	14	44	43	174,588
7	Pickaway	26	36	50	95,094
7	Stark	5	36	52	164,998
9	Trumbull	7	35	35	158,678
10	Mahoning	9	30	36	165,570

DIRECTIONAL DRILLING

Using directional-drilling technology, operators are completing wells in previously unaccessible areas such as acreage covered by water, densely populated urban areas, and wetlands. Typically, a directionally drilled well is drilled vertically to a predesignated depth, then deviated at an angle designed to encounter the producing formation. In 1994, 33 directional-drilling permits were issued to drill wells in seven counties. The most active counties were Mahoning (14), Summit (8), and Trumbull (7). All but three of the directional-drilling permits issued targeted the "Clinton" sandstone and were issued in northeastern Ohio.

COUNTY DRILLING-DEPTH RECORDS

The emphasis on exploration below the Knox uncomformity resulted in three new drilling-depth records. In Fairfield County, a well was drilled 5,924 feet into the Precambrian basement rock, 807 feet deeper than the former record-holding well drilled in 1974. In Muskingum County, a well was drilled 7,270 feet into the Trempealeau dolomite, 360 feet deeper than the former record-holding well drilled in 1947. In Vinton County, a well was drilled 4,894 feet into the Beekmantown, 599 feet deeper than the former record-holding well drilled in 1920.

PRODUCTION

Ohio's total reported crude oil production in 1994 was 8,757,872 barrels, an increase of 475,849 barrels (5.7 percent) from 1993. This gain is due to increased production from the Rose Run sandstone. In 1994, daily production averaged 23,994 barrels. Through 1994, Ohio wells have produced 1,036,925,322 barrels.

Ohio wells produced 130,855,248 MCF of natural gas in 1994, a decrease of 5,083,600 MCF (3.7 percent) from 1993. Gas production figures include an estimated 1,295,596 MCF of natural gas used on the lease. In 1994, daily production averaged 358,508 MCF. Through 1994, Ohio wells have produced 6,955,577,434 MCF of natural gas.

MARKET VALUE

The market value of crude oil decreased 4.7 percent in 1994 to $136,258,819. The average price per barrel was $15.59, a 9.7 percent decrease from the 1993 average of $17.26 per barrel.

Natural gas production was valued at $317,728,937 in 1994, a decrease of 4.8 percent ($16,040,354) from its 1993 value. The average price paid per MCF was $2.45 in 1994, a decline of 3 cents per MCF from 1993.

Ohio's combined oil and gas market value decreased by 4.8 percent ($22,776,756) in 1994. The total dollar value was $453,987,755, the lowest market value since 1978.

PLUGGING ACTIVITY

In 1994, 846 wells were plugged, a 53-well increase from 1993. This total does not include dry holes that were plugged in 1994. Plugging permits continued to exceed drilling permits, a trend that began in 1991, and the number of wells plugged was greater than the number of wells drilled. Wells were plugged in 49 counties, compared to 45 in 1993. Medina County was the most active plugging county (101 wells). The majority of wells plugged in this county were associated with enhanced-recovery projects. Holmes County was second (52 wells), followed by Coshocton (44 wells), Licking (43 wells), Muskingum (39 wells), and Summit (39 wells) Counties.

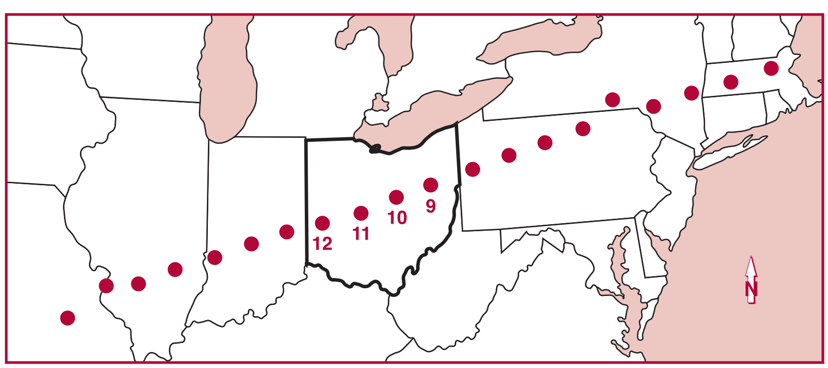
The full, 58-page 1994 report may be obtained for $3.00 from: ODNR, Division of Oil & Gas, 4383 Fountain Square Drive, Columbus, OH 43224, telephone 614-265-6916.

Ohio participates in seismic experiment

Ohio is one of seven states participating in a year-long project to study the interior of the Earth by analyzing waves generated by distant earthquakes. This project uses a line of 20 seismographs stretching from Missouri to Massachusetts, a distance of more than 1,000 miles, and is known as MOMA, incorporating the U.S. Postal Service abbreviations for Missouri (MO) and Massachusetts (MA). These instruments will pick up diffracted waves from earthquakes in seismically active areas such as Tonga and Indonesia in the South Pacific in order to study the structure of the core-mantle boundary, which is important to understanding deep-mantle convection. In addition, body waves from earthquakes in subduction zones in the Aleutian Islands, the Kuril-Kamchatka region of Russia, Peru-Chile, and Central America will be used to study the heterogeneous mineralogical composition of subducted slabs and how they are subducted.

This project is being carried out by Timothy J. Clarke of the University of Illinois, Karen M. Fischer of Brown University, and Michael E. Wysession of Washington University, St. Louis. The seismometers and associated equipment were installed in 1994 and early 1995. Four stations were installed in Ohio in a line from northeast to southwest and are actively collecting data from broadband seismometers. These stations are in Stark, Richland, Union, and Miami Counties. Stored data are periodically retrieved on site from each station, as most of the instruments lack the capability for telemetry.

The Division of Geological Survey has assisted Dr. Clarke with the Ohio portion of the array, particularly with the instrument location in Union County. Instrument sites require security, cultural quietness (away from major highways and railroads), near-surface bedrock, and a location close to a straight line between Missouri and Massachusetts. Site preparations were carried out in October 1994 and the seismometer was installed in March 1995.



Locations of seismograph sites in the Missouri to Massachusetts (MOMA) array.

Of particular interest to the State of Ohio is the fact that these Ohio stations are capable of recording near-source earthquakes, that is, ones that occur within the state boundaries. Although the earthquake records are not immediately retrievable, they can be used in a follow-up analysis to assist in determining the precise location and magnitude of the event. This capability, although it will continue only for a year, provides interim coverage while the Survey attempts to replace the seismic-monitoring capability that was lost in 1992 (see *Ohio Geology*, Summer 1993). On-line Ohio stations in the MOMA array recorded a 3.6-magnitude earthquake in southern Highland County on February 19, 1995. Dr. Clarke will provide seismograms to the Division of Geological Survey for any additional Ohio earthquakes that occur during the operation of his array.

—*Michael C. Hansen*

HANDS-ON EARTH SCIENCE No. 5

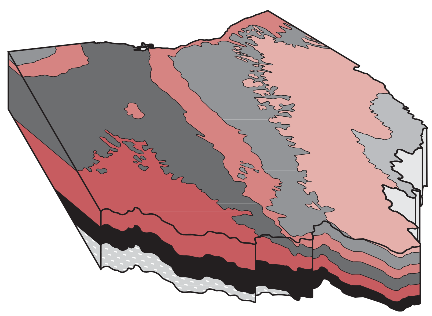
by Joseph T. Hannibal,
The Cleveland Museum of Natural History

MODELING OHIO'S GEOLOGY

Geologic maps are representations of the geology of an area. For example, the geologic map of Ohio shows the distribution of bedrock belonging to six geologic systems, that is, rock laid down during corresponding geologic time periods.

Geologic maps generally are colorful, and commonly are accompanied by cross sections that help in their interpretation. Still, it's not always easy for the student to understand what these maps represent. One hands-on way to help understand such maps is to make your own three-dimensional model. It is quite easy to make such a model of Ohio—all you need is plaster, a mold shaped like Ohio, paints, and a geologic map of Ohio. Many craft stores sell plaster and molds for making plaster objects. If your craft store does not have an Ohio mold, the store can order molds of Ohio and other states from the Deep Flex Plastic Mold Co., Murfreesboro, Tennessee. Their Ohio mold produces casts that are 5.5 x 5.5 x 1.0 cm in size. Multiple molds can be purchased for classroom use. Inexpensive acrylic paints can be used for painting your model. Six colors will be needed for the top view and two additional colors for the cross-sectional view. A simple, page-size geologic map illustrating the geologic systems can be ordered from the Ohio Division of Geological Survey.

To make your three-dimensional model, mix plaster according to the recipe on the container and pour it into the plastic mold. Let it dry for at least two hours. Then, using the geologic map of Ohio as a guide, paint the area representing rock belonging to each geologic system a different color. The top view will be easy—it's the same as the map. The sides of the model will be more difficult, requiring an understanding of the tilting (dip) of the rock layers beneath the surface and a basic understanding of geologic principles. The accompanying illustration will help. When painting your model, be sure to remember



that younger rock layers in Ohio overlie older layers; this is the Law of Superposition. In a classroom, students can either work in small groups or make individual models. The final model can be protected by spraying it with an acrylic fixative. Teachers may want to make a large-scale plaster map; directions for such a map are given in the reference cited below.

Geologic maps also can be made using different colors of play clay or similar materials to represent rocks belonging to different systems. However, because of shrinkage during drying, these models will not be as attractive as well-painted plaster models.

The geological gourmet might prefer to make edible geologic-map cookies. This project requires a state cookie cutter (available, for instance, from the Ohio Historical Society, 1982 Velma Ave., Columbus OH 43211). A simple sugar cookie recipe from any general cookbook can be used. A glaze frosting can be made using powdered sugar, a tad of warm water, and a few drops of food coloring; again, a recipe can be found in any general cookbook. At least six colors of frosting will be needed for a geologic map of Ohio. You can try making three-dimensional cookies by cutting out a thicker than usual cookie. However, if you are not an expert cookie maker you will find it difficult to frost the sides of the cookies, so it may be best to simply do the top view of the map. Add a chocolate chip to identify your city. One warning—making edible geologic maps takes time! If this project is done for the classroom the cookies can be baked at home by the teacher or by parent volunteers the day before frosting in class.

SOURCE: "A simple, inexpensive method for making a three-dimensional geologic model of your state," by Suellen Hopfer and J. T. Hannibal, *in* On the Rocks: Earth Science Activities for Grades 1-8, S. G. Stover and R. H. MacDonald, eds., SEPM (Society for Sedimentary Geology), 1993.

NOTE: Contact Sherry Weisgarber at 614-265-6588 if you are interested in submitting a hands-on activity for this column.

Ohio Geology

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OHIO DEPARTMENT OF NATURAL RESOURCES DIVISION OF GEOLOGICAL SURVEY

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