Ohio Geology
A Quarterly Publication of the Division of Geological Survey — Spring 1994

OIL AND GAS EXPLORATION IN THE ROSE RUN SANDSTONE

by Ronald A. Riley

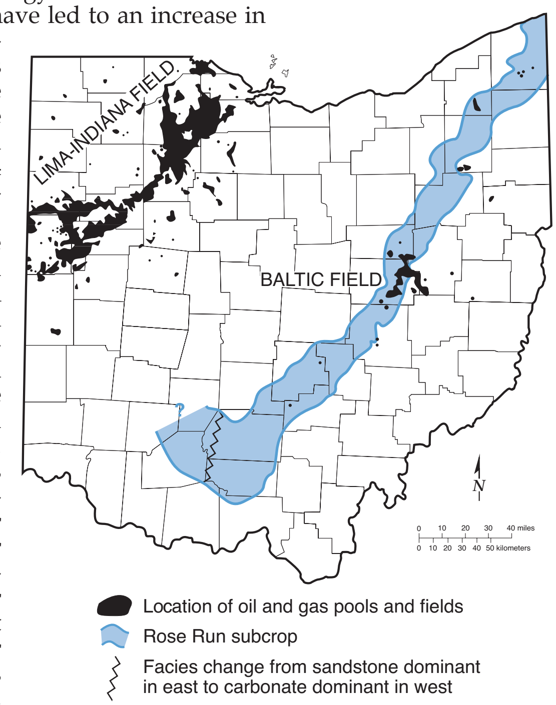
Ohio has played a significant role in supplying our country's ever-increasing demands for energy throughout the history of oil and gas exploration. Since the discovery of the Lima-Indiana field in northwestern Ohio in the late 1800's, Ohio operators have aggressively explored the state for oil and gas. The Lima-Indiana field was the first true giant oil and gas field discovered in North America and supplied the nation with an ample supply of cheap petroleum products at a time when new inventions such as the internal combustion engine were increasing the need for fuels and lubricants. Once again aggressiveness and vision are being called upon by geologists to address the demand for petroleum products to supply our country's energy needs, and once again Ohio is being looked upon to assist in meeting these demands. These attributes are in evidence today in the exploration of yet another elusive geologic target known as the Rose Run sandstone.

To understand the rationale behind Rose Run exploration, one must first understand how and where this sandstone unit was deposited, its internal composition, and the lateral and vertical changes which are present. These lateral and vertical changes in the composition and texture of a geological unit such as the Rose Run are referred to as heterogeneity, and they play a significant role in the distribution of oil and gas. The Ohio Division of Geological Survey and the Pennsylvania Bureau of Topographic and Geologic Survey recently completed a two-year cooperative investigation and a published report on the identification and description of reservoir heterogeneity of the Upper Cambrian Rose Run sandstone in Ohio and Pennsylvania. Information gleaned from this investigation should provide additional insight in ways to explore and better understand this oil and gas target.

HISTORY OF ROSE RUN PRODUCTION

Natural gas was first produced from the Rose Run sandstone in 1965 from the Kin-Ark No. 1 Erb well in Holmes County, Ohio. This discovery well was drilled to a depth of 6,570 feet and had an initial production rate of 2.1 million cubic feet of gas (MMcfg) and 10 barrels (bbl) of oil per day. No one knew at the time, but this well would have a profound impact on the mind-set and exploration strategy of Ohio petroleum explorationists for decades to come. No longer were oil and gas operators drilling only for shallow objectives such as the "Clinton" sandstone, but now their efforts also were focused on deeper exploration targets such as the Rose Run. This exploration strategy continues unabated today and will probably continue through the turn of the century.

As of 1992, the No. 1 Erb had produced over 2.7 billion cubic feet of gas (Bcfg) and 3,400 bbl of oil. By the end of 1993, approximately 150 wells had been drilled in the development of this field, named the Baltic field, and more than 20 Bcfg had been produced. Interest in Rose Run drilling was stimulated in the late 1980's because of dissatisfaction with shallower "Clinton" production and the discovery of numerous high-reserve Rose Run wells. This interest continues today as Ohio drillers put down record numbers of deep tests. From 1983 to 1993 Rose Run drilling increased dramatically. Better understanding of the geology and more advanced exploration techniques have led to an increase in the success rate of locating commercial quantities of oil and gas in the Rose Run. The success rate from 1989 to 1993 showed a steady increase from 24 to 61 percent for productive Rose Run wells.



Map of producing fields and pools in the Rose Run sandstone and Beekmantown dolomite. Location of the historically significant Lima-Indiana field in the Trenton Limestone also shown.

Exploration for the Rose Run has spread across Ohio; production now extends from Pickaway County northward to Ashtabula County and across the border into Crawford County, Pennsylvania. Over 1,200 Rose Run wells have been drilled in eastern Ohio in the quest for this higher risk and higher potential oil and gas target. Although the deeper average depth—6,500 feet compared to 4,200 feet for the "Clinton"—makes this a more costly play, the higher reserves still make it an attractive target. In the Rose Run subcrop trend in Ohio, approximately 34 Bcfg has been produced from the Rose Run and adjacent units through 1992. Although present in eastern Kentucky, the Rose Run has not yet proven to be commercially productive there. A significant gas show, however, was found in the Rose Run sandstone in Lee County, Kentucky, in the Big Sinking field. This well had an initial open flow of 1.6 MMcfg, indicating Rose Run gas potential.

GEOLOGY OF THE ROSE RUN SANDSTONE

The Rose Run sandstone was first named by L. B. Freeman in 1949 from the Judy and Young #1 Rose Run Iron Company well in Bath County, Kentucky. Although there was no commercial oil

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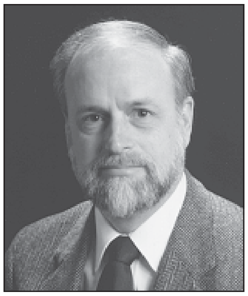

Thomas M. Berg, Division Chief and State Geologist

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From The State Geologist...

Thomas M. Berg

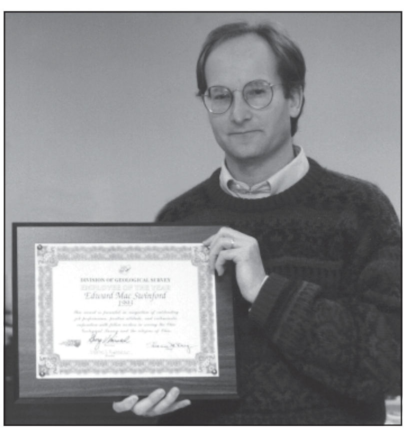
THE UNPREDICTABLE FUTURE OF NATURAL GAS

The U.S. Geological Survey (USGS) has just issued a 890-page volume titled, *The future of energy gases* (Professional Paper 1570, $59.00), that is very important reading for geologists and energy policy-makers. This publication, edited by David G. Howell of the USGS, includes 58 papers by many authors on diverse scientific and economic aspects of natural and synthetic gases in the United States and the entire world.

Of particular interest to me and to readers of *Ohio Geology* is the last paper by Howell, Wiese, and Swinchatt titled, "The gas gap: uncertainty in the supply of natural gas." Their paper tells us that forecasts of natural gas supplies for the next century are extremely variable. We simply do not have a "good handle" on how much natural gas will be available to us and succeeding generations for the next 100 years. One forecaster predicts that by the year 2030, petroleum-powered vehicles will be relegated to museums, and that by the year 2035, all coal-fired and natural-gas-fired electric generating plants will be closed. Another forecaster predicts that natural gas will provide for our energy needs throughout the 21st century and beyond. Other forecasts range between these two extremes. Some believe that solar energy and synthetic hydrogen gas will provide for future energy needs, greatly diminishing society's dependency on carbon-based products.

This issue of *Ohio Geology* focuses almost exclusively on oil and gas resources in Ohio. In McCormac's article on 1993 developments, there is some good news regarding new discoveries in the Rose Run sandstone, but the bad news is that total permitting and drilling are down to 1930's levels. In Riley's article on the Rose Run, we see the value of Geological Survey research on this complex but very important oil and gas target in Ohio. I hope this issue of *Ohio Geology* will increase awareness that the Ohio Geological Survey's information and research are critical to development of reliable energy resources for the coming century.

1993 Employee of the Year



Mac Swinford receives the 1993 Employee of the Year award.

E. Mac Swinford, Head of the Bedrock Mapping Group, was selected as the Survey's 1993 Employee of the Year. This award recognizes superior efforts and contributions by an employee and has special significance because awardees are selected from nominations submitted by Division employees. The award was presented to Mac by Division Chief Thomas M. Berg at the Survey's annual Christmas luncheon. Mac was also recognized as the January 1994 Employee of the Month for the Ohio Department of Natural Resources.

Mac is originally from Columbus, but grew up in Pittsburgh. He joined the Survey in 1983 after receiving a B.A. degree in geology from Ohio Wesleyan University in Delaware, Ohio, and an M.S. degree in geology from Eastern Kentucky University. While at Eastern Kentucky University, Mac served a six-month internship with Mobil Oil Corporation working on the Ohio Shale. After graduation, he worked in the oil and gas industry in Wyoming. Mac mapped the Peebles quadrangle in Adams County for his master's thesis, which prepared him for bedrock mapping at the Survey.

In 1986 Mac was appointed coordinator of the mapping of Lower Paleozoic rocks for the Survey's statewide mapping program and did extensive mapping in Hamilton County. He eventually assumed responsibility for coordinating all bedrock mapping and was recently appointed Head of the Bedrock Mapping Group. Mac has earned the respect of his peers at the Survey for his knowledge and scholarship and for his ability to deal with people and problems in an effective and cordial manner. Mac is a member of the Division's Total Quality Improvement Task Force.

Mac resides in the Columbus suburb of Grandview Heights with his wife, Jane, and three children. Mac enjoys long-distance running as a hobby.

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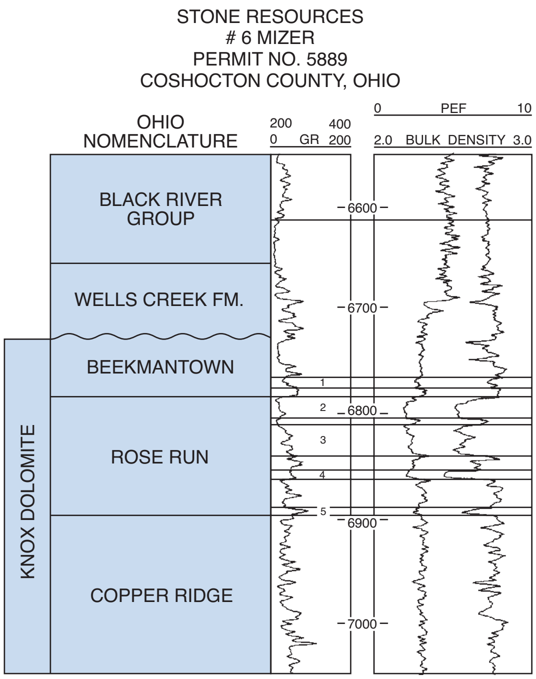
or gas production, a show of gas was reported in the Rose Run, along with much water. By the mid-1960's, several deep tests in eastern Ohio had penetrated equivalent rocks. The name Rose Run was applied by drillers and petroleum geologists to these equivalent-age rocks as a means to subdivide the Knox Dolomite.

To better understand the deposition and composition of the Rose Run, it is necessary to examine the vertically adjacent rocks, which are collectively



Log suite for the Rose Run sandstone and adjacent units for a typical well. Individual sandstone units are labelled 1 to 5. GR, gamma ray; PEF, photoelectric factor.

known as the Knox Dolomite. In Ohio, the Knox consists of the rock units overlying the Eau Claire, Kerbel, or Conasauga Formations and underlying the Knox unconformity. In eastern Ohio the Knox has been subdivided into the following units, in ascending stratigraphic order: the Copper Ridge dolomite, the Rose Run sandstone, and the Beekmantown dolomite. On geophysical logs, the Rose Run sandstone is easily traced in the subsurface of Ohio on the basis of its higher porosity compared to the less porous underlying Copper Ridge dolomite and overlying Beekmantown dolomite. This higher porosity is the reason for the excellent reservoir characteristics.

The Rose Run is a mixed carbonate-sandstone depositional sequence within a very thick carbonate-dominated Knox. A discussion of the depositional setting of the Knox is necessary to understand the present-day distribution of the Rose Run and vertically adjacent units.

During the Late Precambrian and early Paleozoic (approximately 570 million years ago), Ohio and Pennsylvania were part of a large crustal plate, called Laurentia, that occupied a position straddling the Equator. The Iapetus Ocean probably originated in the Late Precambrian, when the northwestern margin of the Baltic plate rifted or broke away from the southern margin of Laurentia. At the time, the southern margin of Laurentia, including the continental shelf area that would eventually become Ohio and Pennsylvania, became a stable continental margin.

During the Early and Middle Cambrian, the Precambrian rocks in much of what is now eastern Ohio and western Pennsylvania were exposed and eroded. Deposition of basal sands on the Precambrian unconformity in Ohio and western Pennsylvania began late in Middle Cambrian time as sea level rose and the southern margin of Laurentia subsided in response to the weight of increasing amounts of sediment. By Middle Cambrian time, the faulted Rome Trough had begun to form along the southern margin of this exposed landmass. Precambrian crustal-block faults in the Rome Trough during Early and Middle Cambrian time probably were derived from stresses during opening of the Iapetus Ocean.

Recycled sands continued to be deposited throughout much of the Late Cambrian from the elevated continental landmass of what is now called the Canadian Shield. By that time they were mixed with the shelf carbonates of the Knox that eventually dominated sedimentation on the shelf. Sandstone composition of the Rose Run suggests that it was derived from the Canadian Shield region, although other source localities are possible. By the end of the Cambrian, deposition of quartz sands had almost ceased, whereas the deposition of carbonates continued unabated.

At some time during the Early to Middle Ordovician, the Iapetus Ocean began to narrow after a change in stresses caused the continental shelf of Laurentia to collide with the Gondwana plate. This collision resulted in the formation of a subduction zone, a region in which one crustal plate descends beneath another. The continental shelf of Laurentia buckled during the initial period of plate collision. It was faulted, folded, and regionally uplifted, initiating a period of erosion that beveled progressively older rocks and sediments from north to south (present east to west). This regional erosional surface is known as the Knox unconformity and had a profound influence on the later entrapment of oil and gas deposits. The western limit of the Rose Run trends through central Ohio and was the result of truncation at the Knox unconformity.

This surface was later submerged during a high stand in sea level during the Middle Ordovician. Post-Knox sediments such as the shales of the Wells Creek Formation (Glenwood Formation) were subsequently deposited on top of this erosional surface or Knox unconformity. These tight shales serve as a seal or a barrier for the entrapment of oil and gas in the Rose Run.

Much of the heterogeneity of the Rose Run is related to the environment in which these sediments were deposited. Upper Cambrian rocks in eastern North America represent deposition on or adjacent to a rimmed shelf. This broad continental shelf was of low relief and was subjected to cyclical sea-level changes. It was these cyclical sea-level fluctuations that in part produced the heterogeneity or variations in the rock composition and texture of the Rose Run and adjacent units of the Knox. Because of the low relief of this rimmed shelf, periodic raising and lowering of sea level by a few tens of feet was probably sufficient to submerge or expose this Knox surface at various times.

Through the study of rock outcrops and from borehole information such as well cuttings, cores, and geophysical logs, we have a recorded history of the environment during the time of Rose Run deposition. Examination of outcrops and subsurface cores drilled through the Rose Run reveal valuable

It is difficult today for many people to visualize Ohio's environment as a hot arid climate with a spectacular ocean view.

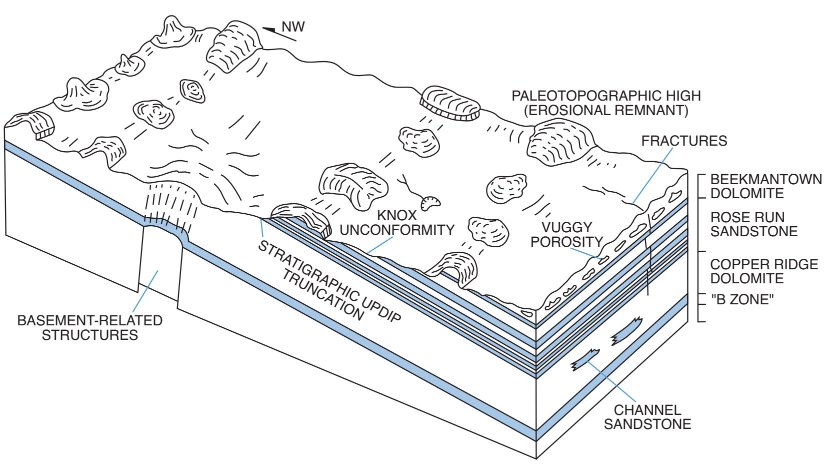
clues in deciphering events which occurred during and following deposition of these rocks.

It is difficult today for many people to visualize Ohio's environment as a hot arid climate with a spectacular ocean view. However, environments can change dramatically over the course of hundreds of millions of years. We now know through the recent study of the Rose Run sandstone that during Late Cambrian and Early Ordovician time (approximately 500 million years ago) these sediments were deposited in a nearshore, arid, shallow-water environment.

Various authors have attributed much of the Knox sediments to a tidal-flat environment and to subtidal environments (below low tide). Tidal flats are nearshore environments that contain features dominated by seasonal tide action. Various features found in Rose Run rocks such as tidal channels, burrows from organisms, mud cracks, algal mounds, and evaporite deposits dominate different regimes of a tidal-flat environment. Modern-day examples of this type of environment include the Persian Gulf and Shark Bay in Western Australia.

TRAPPING MECHANISMS AND POROSITY

Entrapment of oil and gas in the Rose Run and vertically adjacent Knox units (Beekmantown and Copper Ridge dolomites) is controlled primarily by paleotopography—the buried topography of the Knox unconformity. Erosion on the Knox unconformity created an irregular topography of hills and valleys, which are now buried thousands of feet below the surface. These buried hills are referred to as paleotopographic highs or erosional remnants by petroleum geologists and provide an excellent trapping mechanism for oil and gas in the Rose Run. Exploration for these paleotopographic highs is very active where the dipping beds of the Rose Run subcrop or are truncated against the Knox unconformity.



Block diagram illustrating the Knox unconformity and oil and gas trapping mechanisms.

Several types of stratigraphic traps also serve to trap oil and gas in the Rose Run. One of these stratigraphic traps exists where the dipping beds of the Rose Run are truncated updip against the Knox unconformity. The overlying Wells Creek Formation (Glenwood Formation) serves as an effective seal or barrier for trapping these hydrocarbons. Narrow channel deposits of sandstone which are encased by tight dolomite also serve as important traps.

A requirement for the accumulation of oil and gas in rocks such as the Rose Run is the presence of porosity. Porosity is the amount of pore or void space between the cemented grains that compose a rock. The Rose Run sandstone has well-developed porosity, but adjacent units such as the Beekmantown dolomite typically are much tighter and less porous. Natural fractures and enlarged cavities, called vugs, enhance porosity and provide a good reservoir for trapping oil and gas. Vuggy porosity in the Beekmantown dolomite is created by the downward percolation of surface waters which chemically react with and dissolve carbonates.

Deeper structures (faults and folds) in the lowermost section of rocks in the Earth's crust, called the basement, also may have an impact on the overlying Knox units. These basement-related structures create structurally high features deep in the subsurface which serve to trap the upward-migrating oil and gas.

EXPLORATION TECHNIQUES

These various oil and gas traps in the Rose Run are explored using a number of techniques, including log analysis, construction of subsurface structure and isopach maps, and interpretation of seismic reflection data.

Analysis of geophysical logs allows petroleum geologists to better understand the rock composition and the amount of pore space in rocks that contain oil and gas. Geophysical logs can be correlated from well to well across large distances to construct subsurface maps to better delineate the distribution of rock units.

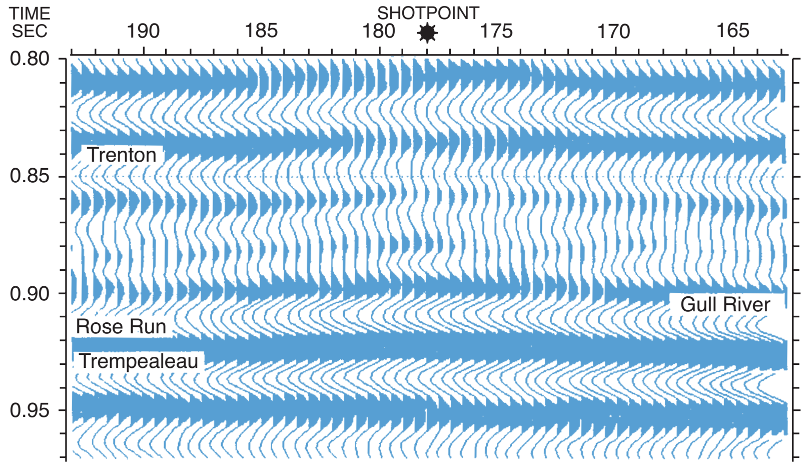
Subsurface structure maps on the Knox unconformity are helpful in identifying buried hills. In areas where deep well control is not available, shallow well control, such as "Clinton" wells, is used for mapping. These shallow strata in some instances reflect the deeper structures and are useful in locating buried Knox hills.

Isopach (thickness) maps are used to determine the areal distribution of various rock units such as the Rose Run and to predict trends where data are unavailable. Isopach maps also help geologists to develop a better understanding of environments in which these sediments were deposited.

Seismic reflection is an invaluable advanced geophysical tool for exploration of oil and gas in the Rose Run. The seismic reflection procedure is based on the principle that acoustic energy (sound waves) can be transmitted through the subsurface and measured at the Earth's surface. A source of acoustic energy is placed at or just below the surface. Because the source is generally an explosive, it is referred to as a "shot." After source detonation, the energy spreads out in all directions. Some of this energy returns to the surface and is detected by receivers called geophones. The output from these receivers is measured as a function of time. A plot of the output from one receiver is called a trace, and many traces are combined to form a continuous seismic profile of the subsurface. These seismic profiles provide geophysicists and geologists with a two-dimensional profile or cross section of the Earth, miles below the surface. Recent advanced seismic prospecting uses three-dimensional seismic profiles. This technique has not yet been used in Ohio, but probably will be in the near future for Rose Run exploration.

Because of limited deep well control, seismic exploration has played a significant role in the search for subtle hills buried deep in the subsurface. Many of these buried hills or Knox erosional remnants have 40 feet or less of relief. Research is continuing to improve the seismic identification and recognition of these erosional remnants.

Seismic reflection data reveal these buried hills as subtle, low-relief features from the Copper Ridge ("Trempealeau") up to the Trenton (Middle Ordovician) reflector. On the accompanying seismic line, there is an attenuation (breakup) of the Trenton reflector over these buried hills. An amplitude change at the Gull River reflector indicates a probable change in the rock composition. This change is referred to as an "eyebrow" anomaly. A well drilled at shotpoint 178 penetrated the Copper Ridge dolomite ("Trempealeau"). A thick section of Beekmantown was encountered and no Wells Creek Formation. This well was completed successfully in the Rose Run sandstone.



Seismic line illustrating a Beekmantown remnant (from Roth, Bryan, 1992, Seismic modeling of Ordovician Rose Run/Beekmantown dolomite oil and gas traps in east-central Ohio, unpublished M.S. thesis, Wright State University, 84 p.).

FUTURE TRENDS

In terms of oil and gas exploration and development, the Rose Run sandstone and adjacent units in the Knox are one of the brightest spots in Ohio. The Rose Run is currently the most active exploratory oil and gas play east of the Mississippi and has potential along the entire subcrop from south-central Ohio to northwest Pennsylvania and into New York. Oil and gas potential also is evident from significant shows from the Rose Run in northeast Kentucky and in extreme eastern Ohio, where limited deep drilling has taken place. High-risk, high-potential targets may exist in the Rome Trough in Pennsylvania and West Virginia. In the Rome Trough in southwest Pennsylvania, the thickness of the Rose Run sandstone exceeds 700 feet at depths greater than 21,000 feet. Areas of Knox production also exist in south-central Kentucky.

Log analyses indicate exploration potential in the Beekmantown dolomite along a trend which roughly parallels and extends at least 12 miles east of the Rose Run subcrop. Oil and gas potential also exists in fractured zones along major fault trends such as the Akron-Suffield fault system and the Highlandtown fault system in north-central Ohio.

Advanced geophysical analyses, including seismic modelling and three-dimensional shooting, will aid in identifying Knox stratigraphic traps and paleotopographic highs. Through the ever-increasing advanced technology used by petroleum explorationists, and through their vision, our state's oil and gas needs will continue to be met for decades to come.

FURTHER READING

Janssens, A., 1973, Stratigraphy of the Cambrian and Lower Ordovician rocks in Ohio: Ohio Division of Geological Survey Bulletin 64, 197 p.

Riley, R. A., Harper, J. A., Baranoski, M. T., Laughrey, C. D., Carlton, R. W., 1993, Measuring and predicting reservoir heterogeneity in complex deposystems: the late Cambrian Rose Run sandstone of eastern Ohio and western Pennsylvania: Report prepared for U.S. Department of Energy, contract no. DE-AC22-90BC14657, 257 p.

1993 OHIO OIL AND GAS DEVELOPMENTS

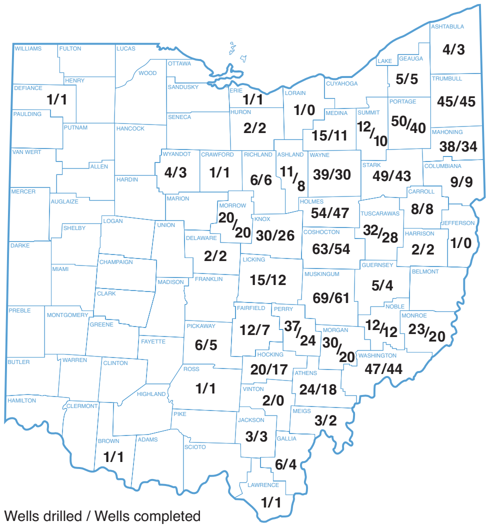
by Michael P. McCormac
ODNR, Division of Oil & Gas

1993 was a year of extremes, perhaps more than in any recent year, for the oil and gas industry in Ohio. The good news is a record number of wells were drilled to the Rose Run sandstone, exceeding the previous high by approximately 120 wells. The bad news is permitting and drilling levels were the lowest since the 1930's. Hand in hand with the Rose Run record was the end of the gradual shift from drilling "Clinton" sandstone wells to drilling Rose Run wells. The big question for 1994 is: Will there be more Rose Run wells drilled than "Clinton" wells? Early activity in 1994 indicates this circumstance will probably happen.

Overall, permitting activity again declined, continuing the trend that began in 1985. The Division of Oil & Gas issued 2,135 permits in 1993, a decline of 14 percent (346) from 1992. This total includes permits issued to convert, deepen, drill, plug back, plug and abandon, reissue, and reopen. Drilling permits accounted for most of this decrease. Historically, the last quarter has been the busiest time for permitting activity. This outcome was not the case in 1993. Low crude oil prices and the expiration of the Tight Formation Tax Credit in 1992 were key factors stunting activity.

In 1993, fewer than a thousand (904) drilling permits were issued, a 23.7 percent decline from last year. These permits included 802 new permits and 102 reissue permits. Deep well permits were the bright spot, increasing 21.7 percent (85) and accounting for 48 percent of all new well permits. Deep well permits are permits issued to formations below the Knox unconformity, such as the Rose Run, Trempealeau, and Mt. Simon.

Only 822 oil and gas wells were drilled in 1993, a decrease of 52 wells (6 percent). For the second time (1992 was the first) since 1938 the total fell below the 1,000-well mark. This year's total is the



New wells drilled for oil and gas in Ohio in 1993, by county.

lowest since 1935, when 736 wells were drilled. Wells were drilled in 46 of Ohio's 88 counties, an increase of one county from 1992.

The majority of wells (633; 91 percent) were drilled by rotary tools. Cable-tool rigs drilled 62 wells and operated in 18 counties. Cable-tool depths ranged from 312 to 5,519 feet. The average depth per well drilled by cable tool was 2,398 feet; rotary-drilled wells averaged 4,956 feet.

The number of owners drilling wells declined by only four. Well-completion records show that 181 owners drilled wells; 92 percent (167) of these owners drilled 10 or fewer wells, including 70 owners who drilled only one well. These 167 owners accounted for 63 percent (440) of the wells drilled. The highest number of wells drilled by a single owner was 29.

Ohio oil and gas owners/operators submitted 695 well completions, representing 84 percent of the wells drilled in 1993. These reports showed that 532 wells were productive and 163 were dry holes, for a 76.5 percent completion rate. Average well depth was 4,727 feet, an increase of 625 feet per well from 1992. Total depths ranged from 312 feet in the Cow Run sandstone (Athens County) to 9,234 feet in the Rose Run sandstone (Washington County). Fourteen additional reports were received for other types of drilling operations.

Approximately 22 percent (149) of all wells completed were classified as exploratory wells. Sixty were completed and 89 were dry holes, representing a 40.3 percent success rate, an increase of 5 percent from 1992. Wells drilled below the Knox unconformity accounted for 97 percent (144) of all exploratory drilling; 55 of these wells (38 percent) were productive. The Cambrian Rose Run accounted for 91 of these wells; 37 were productive. The Cambrian Trempealeau had 43 exploratory tests, of which 17 were productive.

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 seven different geologic zones ranging from the Pennsylvanian Maxton sandstone to the Cambrian Rose Run sandstone. Generally, the number of wells drilled from the Pennsylvanian to Silurian declined, and producing zones from the Ordovician to the Precambrian increased. "Clinton" sandstone drilling declined 36 percent, accounting for the significant decline in the number of wells drilled this year.

1993 DRILLING OPERATIONS BY TYPE OF WELL

Type of hole	*Drilled*	*Converted*	*Total footage*
Productive wells	532	1	2,462,549
Dry holes	163		823,040
Reopened wells	4		0
Lost holes	6		18,591
Gas storage wells	2	0	4,700
Conventional brine-injection wells	2		6,000
Enhanced-recovery wells	0	25	0
Solution-mining wells	0	0	0
TOTAL	709	26	3,314,880

"Clinton" sandstone

In spite of the decline, the Silurian "Clinton" sandstone has remained the most actively drilled zone since 1965. Forty-one percent (286) of the total wells were completed in this zone, the lowest number of "Clinton" wells completed since at least 1950 and most likely since the early 1930's. "Clinton" sandstone wells had a 97.5 percent completion rate and averaged 4,645 feet in depth, an increase of 117 feet per well from 1992. "Clinton" wells were drilled in 26 counties. The top three counties for "Clinton" drilling were Trumbull (45), Stark (42), and Mahoning (34). Overall, Clinton drilling declined in 20 counties. The greatest declines took place in Portage County (23 wells drilled) and Summit County (20 wells drilled).

Rose Run sandstone

Drilling to the Cambrian Rose Run sandstone broke the 200-well mark for the first time. By the reporting deadline, 219 completion reports had been received; that number is expected to increase to 260. There were almost as many producing Rose Run wells (133) in 1993 as total wells (135) in 1992. The productive rate continued to increase: it has risen from a low of 24 percent in 1989 to a high of 61 percent in 1993. Rose Run wells were drilled in 16 counties by 65 operators, an increase of 5 counties and 23 operators. The average depth per well was 6,068 feet. Muskingum County led with 44 wells, followed by Coshocton (39), Holmes (37), Portage (28), and Tuscarawas (22). The hottest spot was Randolph Township, Portage County, followed by Mechanic Township, Holmes County; Cass Township, Muskingum County; and Washington Township, Coshocton County. Overall, 15 townships had first-time producing Rose Run wells.

Although 80 percent of Ohio's estimated 1,176 Rose Run wells have been drilled since 1983, the significant upturn in activity began seven years ago. Since 1987, 869 Rose Run wells have been drilled in 23 counties. In 1993, only 29 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" sandstone as a back up.

Trempealeau dolomite

Wells completed to the Cambrian Trempealeau dolomite increased by 13 to 79 in 1993. Morrow County continued to be the most active county (19 wells), followed by Wayne County (15 wells). Trempealeau drilling occurred in 16 counties, an increase of 5 from 1992. Trempealeau production was discovered for the first-time in five townships. Forty-three percent of all Trempealeau wells were completed as productive. The average depth per well was 4,705 feet.

Berea Sandstone

The Mississippian Berea Sandstone ranked fourth among producing formations; 47 wells were completed in 13 counties. Washington County had the most Berea wells (18). In addition, nine wells were dual-completed in the Berea Sandstone and the Ohio Shale in the following counties: Monroe (4), Noble (3), and Washington (2). The average depth per well was 756 feet.

Devonian shale

Drilling in the Devonian Ohio Shale declined 39 percent in 1993; 30 wells were completed, compared to 43 in 1992. Monroe County led Ohio Shale drilling with 19 wells. The average depth per well rose to 2,635 feet from 2,109 feet in 1992.

TEN MOST ACTIVE COUNTIES

Muskingum County led the 1993 top-10 list with 69 new wells drilled, a gain of 23 wells from 1992. Drilling in Coshocton County increased by 22 wells, moving it into second place. For the fifth time in the last six years the first-ranked county had fewer than 100 wells drilled; the exception was Monroe County in 1989. Before 1988, the last time the top-ranked county had fewer than 100 wells was 1961.

Top-10 counties are distributed throughout eastern Ohio in areas where the "Clinton" sandstone or the Rose Run sandstone is being drilled. Nine of 10 counties retained top-10 status from 1992. Morgan County dropped from the 1993 list, and Wayne County joined the list. Wayne County was last ranked in the top-10 in 1990.

TEN MOST ACTIVE COUNTIES

1993 rank	*County*	*1992 rank*	*Wells drilled*	*Permits issued*	*Footage drilled*
1	Muskingum	5	69	79	320,846
2	Coshocton	9	63	65	292,872
3	Holmes	3	54	64	266,983
4	Portage	3	50	71	260,492
5	Stark	5	49	59	212,607
6	Washington	1	47	59	149,988
7	Trumbull	7	45	40	211,404
8	Wayne	11	39	43	167,243
9	Mahoning	7	38	43	185,809
10	Perry	9	37	47	91,807

DIRECTIONAL DRILLING

Directional drilling targets areas where vertical drilling cannot be used, for example, acreage covered by water, areas restricted by zoning requirements, or environmentally sensitive areas such as wetlands. A directionally drilled well commonly is drilled vertically to a predesignated depth, then deviated at an angle designed to encounter the producing formation.

Applications for directional-drilling permits increased by one from 1992. Before 1989, the division issued fewer than 3 directional drilling permits per year. Issuance increased to seven in 1989, doubled to 14 in 1990, and nearly tripled to 41 in 1991. In 1993, 40 permits were issued in 9 counties. The most active counties were Mahoning (14), Trumbull (7), Portage (6), Stark (5), and Summit (4). All except four of the directional-drilling permits issued targeted the "Clinton" sandstone and were issued for northeastern Ohio. Three directional drilling permits were issued to drill under Berlin Reservoir, which has been leased from the U.S. Bureau of Land Management.

PRODUCTION

Ohio's total reported crude oil production was 8,282,023 barrels, a decrease of 914,688 barrels (10 percent) from 1992. Through 1993, Ohio wells have produced 1,028,167,450 barrels.

Ohio wells produced 135,938,848 MCF of natural gas, a decrease of 8,876,590 MCF (6.1 percent) from 1992. Gas production figures include an estimated 1,345,929 MCF of natural gas used on the lease. Through 1993, Ohio wells have cumulatively produced 6,824,722,186 MCF of natural gas.

MARKET VALUE

The market value of crude oil decreased 18.1 percent in 1993 to $142,995,220. The average price per barrel was $17.26, a 7.7 percent decrease from 1992's average price of $18.70 per barrel.

Natural gas production, valued at $333,769,291, decreased 0.9 percent ($2,901,622) from its 1992 value. The average price paid per MCF was $2.48 in 1992, a rise of 13 cents per MCF from 1992.

Ohio's combined oil and gas market value decreased by 6.8 percent ($34,372,581) in 1993. The total dollar value was $476,764,511, the lowest market value since 1978.

PLUGGING ACTIVITY

In 1993, 793 wells were plugged, a 113-well decrease from 1992. Wells were plugged in 45 counties, compared to 46 in 1992. Perry County continued as the most active plugging county (73 wells), followed by Licking (67). Muskingum County, second in 1992 (60 wells plugged), only had 26 wells plugged in 1993. This drop may be explained by the Rose Run activity in Muskingum County, which is delaying well plugging in order to retain the acreage for Rose Run sandstone exploration.

SUMMARY

The gradual shift, over the last three years, in permitting and drilling from the "Clinton" sandstone to the Rose Run sandstone (and other deeper formations) ended this year. Deep well permits increased 21.7 percent and accounted for 48 percent of all drilling permits issued. Drilling to the Rose Run sandstone broke the 200-well mark for the first time—an estimated 260 wells were drilled. Trempealeau drilling increased by 13 wells. Overall, 15 townships had first-time producing Rose Run wells, and 5 townships had first-time producing Trempealeau wells.

Although the total number of wells declined, 46 counties had drilling. Directional drilling remained active, accounting for 40 wells. Top-10 counties were distributed throughout eastern Ohio. Wells drilled to the Rose Run sandstone accounted for the majority of wells in the top four counties.

Overall, Ohio now has 64,622 active wells and 3,721 well owners. In 1993, these wells produced over 8 million barrels of oil, and nearly 136 billion cubic feet of natural gas. The market value of Ohio's oil and gas production exceeded $476,000,000.

The full 41-page report, *1993 Ohio oil and gas developments*, may be obtained for $3.00 from: ODNR, Division of Oil & Gas, 4383 Fountain Square Drive, Columbus, OH 43224, telephone 614-265-6916.

OHIO TRIVIA

The first giant oil & gas field in North America was discovered near Findlay, Hancock County, in the 1880's.

HANDS-ON EARTH SCIENCE No. 2

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EGG TECTONICS

Plate tectonics, or the continental drift theory, was first suggested in 1912 by the German scientist Alfred Wegener. The theory, which states that the Earth's surface, or crust, is divided into six to nine major plates that slowly move and change in size, was not widely accepted until the late 1960's. The theory supposes that all the continents were once part of a supercontinent called Pangaea. This theory explains why continents that are now widely separated from each other possess rocks and fossils of the same extinct plants and animals. Geologic events and features such as earthquakes, volcanoes, mountain ranges, hot springs, and geysers also can be explained using plate tectonics.

The slow (1-4 cm per year) movement of tectonic plates causes one of three types of boundaries: *divergent boundaries,* where plates separate; *convergent boundaries,* where plates collide; and *transform boundaries,* where plates slide past each other. The following activity simulates these plate boundaries using a cracked eggshell.

Materials:

3 (or more) hard-boiled eggs
3 (or more) water-based markers

Gently tap the eggs repeatedly on a table while rotating them to produce cracks all around the eggs. Trace along the major cracks with a water-based marker. Gently squeeze the eggs until slight movement of the shell pieces occurs. Look for places where pieces of the eggshell separate. This area represents a divergent boundary. Most divergent boundaries on the Earth are hidden beneath the oceans and are characterized by volcanism, earthquakes, and massive heat flow due to molten rock (magma) rising up from the mantle, which is the thick layer of rock separating the crust from the core at the center of the Earth. The Mid-Atlantic Ridge on the bottom of the Atlantic Ocean is an example of a divergent boundary; here the North American Plate and the Eurasian Plate are separating, causing sea-floor spreading and new oceanic crust to form. Next, look for places where two pieces of eggshell are colliding. This area represents a convergent boundary. Two events can occur when plates converge. If denser oceanic crust collides with lighter continental crust, the oceanic crust will buckle under the continental crust down into the mantle. This process is called subduction and is characterized by earthquakes, rock deformation, and volcanism. The volcanic Cascade Range of the Pacific Northwest was formed by subduction of the Juan de Fuca Plate under the North American Plate. If two equally dense continental crusts collide, both plates will resist being subducted. In this process, the continental crust folds and deforms into a mountain range. The Himalayas are an example of a mountain-building episode which began 25 million years ago and is still occurring today as India travels northward, colliding with Asia. Finally, look for places where one piece of eggshell slides past another. This area represents a transform boundary. The crust is not destroyed here as it is at a convergent boundary, nor is crust created as it is at a divergent boundary. As the two plates slide past each other, earthquakes occur. The San Andreas fault in California is an example of this type of boundary.

NOTE: After this experiment, use the eggs to illustrate the layers of the Earth. Cut the egg in half. The shell represents the crust. The thick egg white represents the mantle. The egg yolk represents the core.

SOURCE: *Terrific Science & Math* (Miami University), Fall 1993, and *Earth and Its Resources,* Creative Teaching Press.

New publications list for educators

The *List of educational resources of the Ohio Division of Geological Survey and sources of additional information* includes educational resources of the Survey and of the Ohio Department of Natural Resources, plus other sources of information for kindergarten through college teachers, such as activity books, science books, catalogs, videos, workshops, and speakers. Prices of materials are included; however, many of the resources are free. To obtain a free copy of the list contact the Geologic Records Center at 614-265-6576.

Ohio Geology

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OHIO DEPARTMENT OF NATURAL RESOURCES DIVISION OF GEOLOGICAL SURVEY

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