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WALLACE W. HAGAN
Director and State Geologist

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SPECIAL PUBLICATION 8

College of Arts and Sciences
UNIVERSITY OF KENTUCKY

LETTER OF TRANSMITTAL

October 1, 1964

Dean M. M. White
College of Arts and Sciences
University of Kentucky

Dear Dean White:

Technical papers presented at the 1962 and 1963 meetings of the Kentucky Oil and Gas Association are presented in this volume for the use of people vitally interested in our tremendously important oil and gas exploration and development industry, which ranks second in value of production among Kentucky's important extractive mineral resources.

We encourage those associated with the industry to continue the presentation of such valuable papers.

Respectfully,

WALLACE W. HAGAN
Director and State Geologist
Kentucky Geological Survey

FOREWORD FOR 1962 PROCEEDINGS

Again this year our technical papers were of the highest quality, and we are deeply indebted to each of those persons who was willing to give that extra effort necessary to prepare and present them, and submit them for publication.

The co-chairmen of our technical sessions, Mr. W. W. Wallen, Vice President in Charge of Operations, Kentucky West Virginia Gas Company, and Mr. Roscoe E. Wise, Assistant Chief Geologist, Sun Oil Company, are to be congratulated for the fine manner in which they arranged for and presided over these sessions.

There is such an abundance of good fellowship at our annual meetings that we might overlook some of the valuable contributions of our organization to the industry, including the instructive papers presented at our technical sessions. To preserve these for the membership and other interested persons, Mr. Preston McGrain and other members of the Kentucky Geological Survey staff have, from year to year, gathered and published these papers in brochure form. This is a valuable contribution to our cause, for which we are most thankful.

E. E. CLARK, President, 1962
Kentucky Oil and Gas Association

FOREWORD FOR 1963 PROCEEDINGS

An annual meeting of our Kentucky Oil and Gas Association has been held for over thirty years. Many people have contributed of their time and effort to making these meetings successful through the years. One of the highlights each year is the Technical Session.

During our 1963 meeting Mr. John Avila and Geo. R. Thomas acted as co-chairmen of the Technical Session. Mr. Avilla is Chief Geologist with Ryan Oil Company of Evansville, Indiana. Mr. Thomas is geologist with United Fuel Gas Company in Prestonsburg. Both gentlemen are to be congratulated for the very competent manner in which they arranged and presided over these sessions.

We are also tremendously indebted to each of these persons who prepared and presented the technical papers. The high quality papers presented at our Technical Sessions are valuable contributions to the organization and to our industry. The Association membership and all other interested persons are indebted to Mr. Preston McGrain and the entire staff of the Kentucky Geological Survey who have from year to year assembled and published these papers in brochure form. To these people and to all of those who have given that extra effort which has contributed so much to making our annual meetings a success we are most thankful.

GEO. A. HUFFMAN, President, 1963
Kentucky Oil and Gas Association

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TECHNICAL SESSION 1963

RECENT DEVELOPMENTS IN OIL AND GAS EXPLORATION IN SOUTHWESTERN BUTLER COUNTY, KENTUCKY

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ABSTRACT

Within the past year there has been quite an increase in drilling interest centered in the area around the common corner of Carter coordinates G & H-31 & 32 in extreme southwestern Butler County. This area has been actively drilled since World War II. Roundabout pool is a newly discovered area of Tar Springs, Hardinsburg and Jackson sand production which is primarily dependent on local stratigraphic traps. Faults and fractures are of no particular significance to local oil production. It may be reasonably assumed, on the basis of like production from nearby pools, that the area should produce an average of a little over 100 barrels per acre-foot of productive saturated sand whether it be Tar Springs, Hardinsburg, Jackson or any combination of the three. Recently introduced "water fracturing" completion methods should materially affect the rate of production but not the total amount of producible reserves.

INTRODUCTION

Within the past year there has been quite an increase in drilling interest centered in the area around the common corner of Carter coordinates G & H-31 & 32 in extreme southwestern Butler County. The general vicinity has been rather sporadically drilled for many years; however, any effort to assemble a complete or accurate history of the area reveals a striking commentary on the nature of much of the past drilling done in southern and southwestern Kentucky. Lost, incomplete, and inaccurate records are so commonplace as to rather strongly discourage geologic investigations concerning the nature of known pools, much less allow for exploratory efforts. The recently adopted oil and gas law is a major contribution to the solution of many geologic problems which have become evident in the preparation of even a short paper such as this. Because so much of the data used here predates the oil and gas law, no inference is made as to complete coverage of past drilling efforts. It is felt, however, that sufficient reasonably accurate data is available to allow the development of a fairly correct, though somewhat general, geologic picture of the area.

HISTORY

Throughout eastern Muhlenberg and western Butler Counties drilling has been fairly slow but steady since World War II. A small McClosky pool was drilled in southeastern G-31 just north of Lewis-

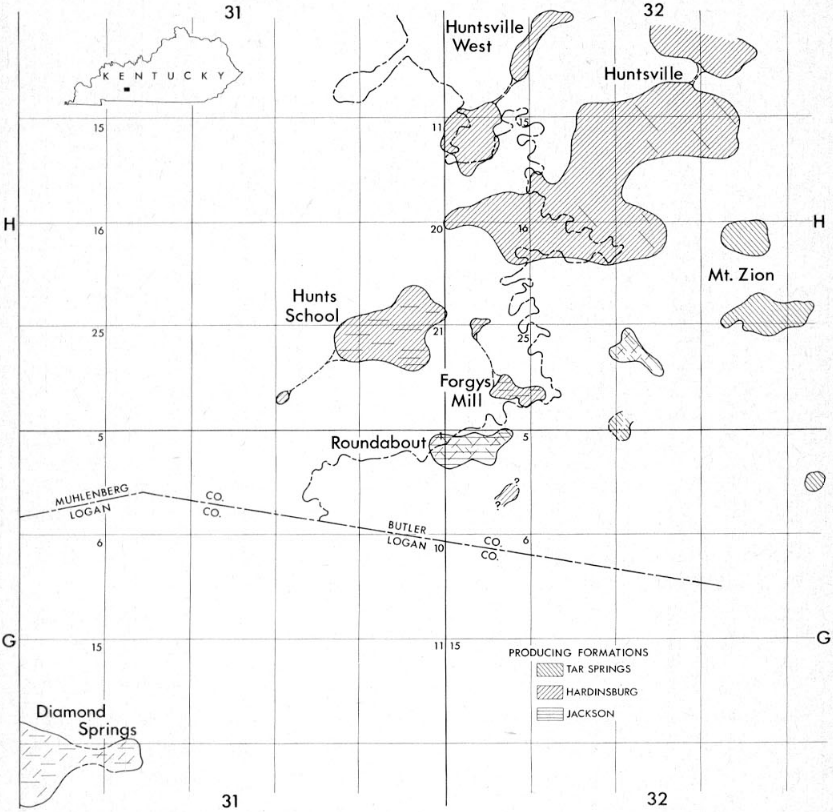

Fig. 1. Map of southwestern Butler County showing productive areas.

burg in 1947. Jackson and McClosky production was found near Diamond Springs in southwestern G-31 in 1949. Evidently considerable drilling was also done in the Huntsville pool area, west central H-32, at about this time. Many small pools such as Mt. Zion, Hunts School, Forgys Mill, Silver City and others are located just north and east of the new drilling discussed here. The name "Roundabout," after a local swamp, is suggested for the newly developed productive area discussed here.

STRUCTURE

Southwestern Butler County is located along the extreme southeast flank of the Western Kentucky coal basin. Subsurface formations generally strike in a northeast direction with northwest dips of from 50 to 100 feet per mile. Superimposed on this regional pattern are anticlinal and synclinal folds of low relief (25 to 50 feet), whose axes trend north-northeast and appear to plunge gently northward. The general pattern of these "folds," or locally positive and negative areas, rather strongly suggests that they are in part truly structural and in part the result of compaction-draping of the various marker horizons over subjacent relatively thick sands.

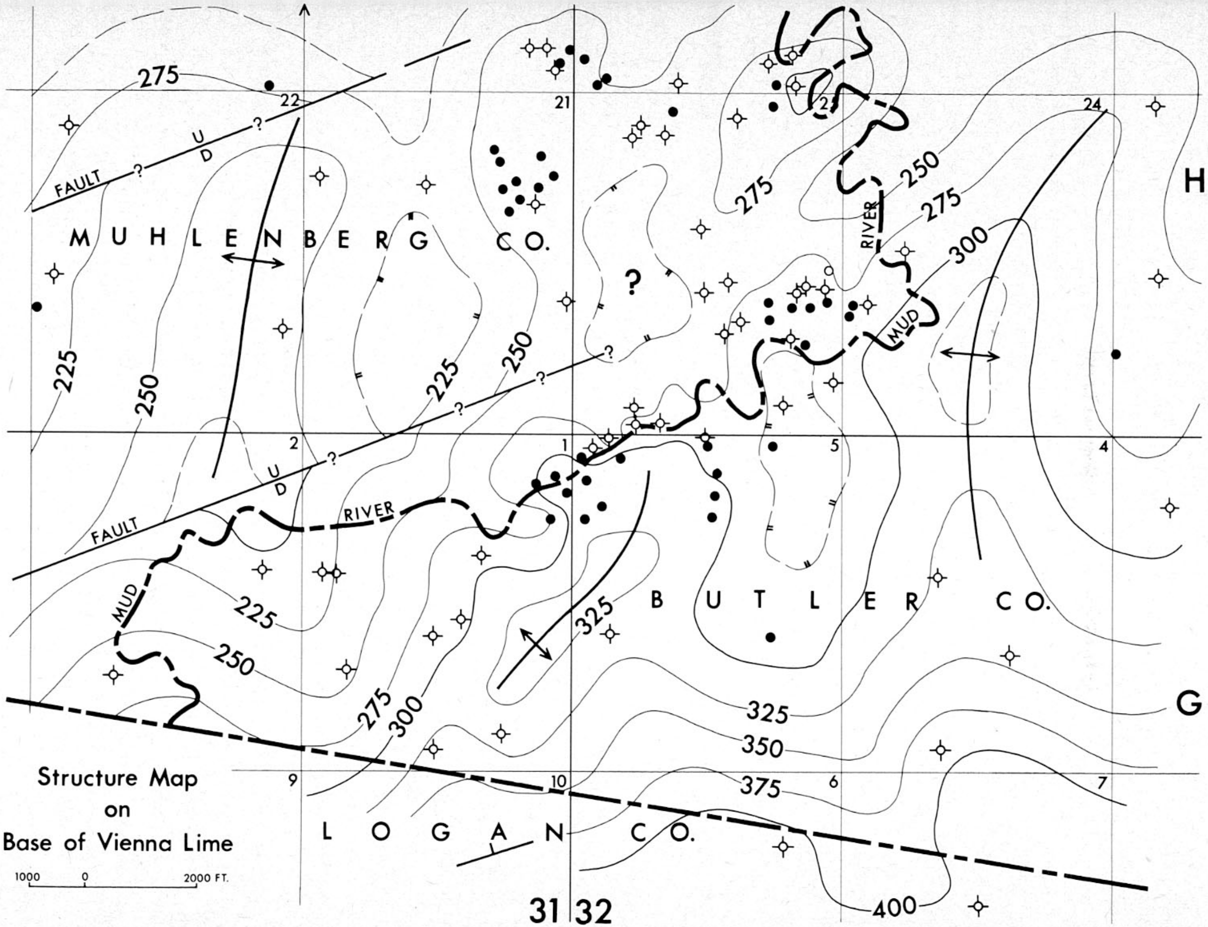

Fig. 2. Structure map of Roundabout pool area with contours on base of the Vienna Limestone. Contour interval is 25 feet.

STRATIGRAPHY

Rose and Cathey's typical stratigraphic column for the H-29 area* very closely resembles the local formational sequence and character. Uplands are capped by an unconformable basal Pennsylvanian conglomerate. Because the first Mississippian formations found below the basal Pennsylvanian range from Menard to Vienna in age, many miscorrelations occur, particularly in the older records. This situation is aggravated by the rather common local variability of the sandy members of many formations. One of the best local formation markers is a relatively consistent red shale member of the Hardinsburg; other red shales occur in the Jackson and the Cypress. It was found by the writer that much so-called "Tar Springs" production was actually Hardinsburg, particularly in the Forgys Mill pool area in 25-H-32. Most of the production in southwestern Butler County is from the Hardinsburg and/or Jackson sands. Reportedly the best nearby Tar Springs production occurs in the Mt. Zion pool in 19-H-32. Production is principally the result of favorably combined local "structure" and stratigraphic traps. In all cases where available data allowed checks to be made, productive pools were bounded up-dip by intra-formational tight, silty to shaly intervals. Since production shows no evidence of direct association with structurally high areas, it is suggested that primary exploratory attention be given to local stratigraphic interpretations.

Within individual productive pools, normal gas, oil, and water contact horizons occur relative to local structural elevations in a single productive sand body but even here there is vague evidence of a relationship between productivity and variations in effective porosity and permeability. This may be a possible reason for one well producing oil from a horizon structurally below an offset water-productive dry hole. Because primary production from many of the smaller pools is almost exclusively the result of gas-expansion drive, the pools flood well and often produce more oil by secondary recovery methods than they did initially; Mt. Zion is an example. This is particularly evident where careful spacing and conservation practices weren't used.

Roundabout pool is producing from both the Hardinsburg and the Jackson sands. Saturated sand thicknesses range from 10 to 20 feet in either of the two productive formations. While water is produced along the structurally lower, northern, side of the pool it appears that much of the productive energy is from solution gas which occurs in sufficient quantity to run the pumps and heater

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* Lithologic Log, Structure Map of Greenville Quadrangle, W. D. Rose, Ky. Geol. Survey, Ser. X, 1960.

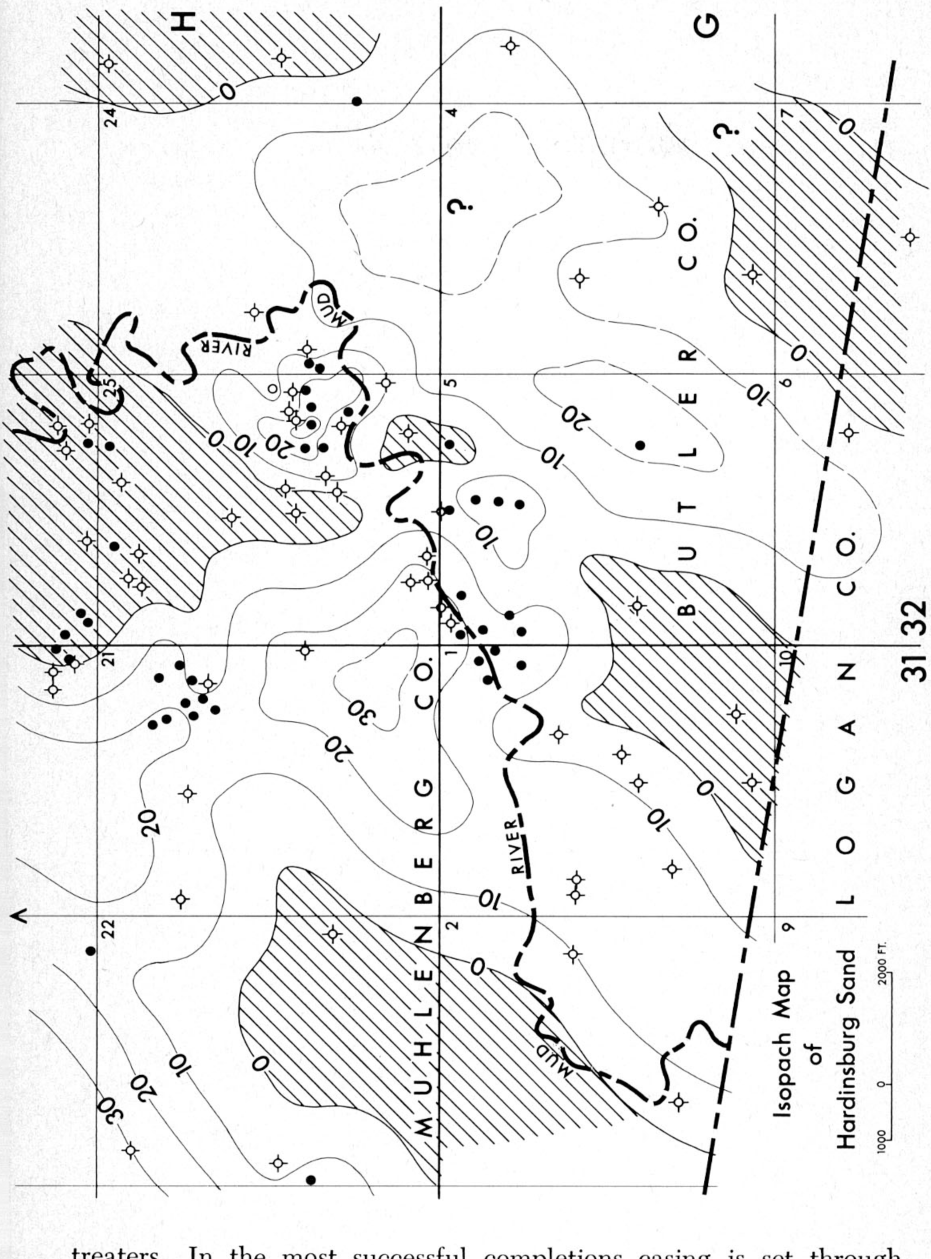

Fig. 3. Isopach map showing thickness of the Hardinsburg sand in the Roundabout pool area. Contour interval is 10 feet.

treaters. In the most successful completions casing is set through the productive interval; the casing is selectively notched and the formation is "water fraced" with various quantities of water and "all the sand the formation will take," which is often one pound or more of sand per gallon of water used. Fresh water is used as a carrier for the propping agent because of in-place water-soluble salts. The effective porosity and permeability are increased by solution of in-place salts as well as by fracturing and propping of the area around the bore hole. There is little evidence that the wells ever really "settle down" to consistent production rates. At first, individual wells

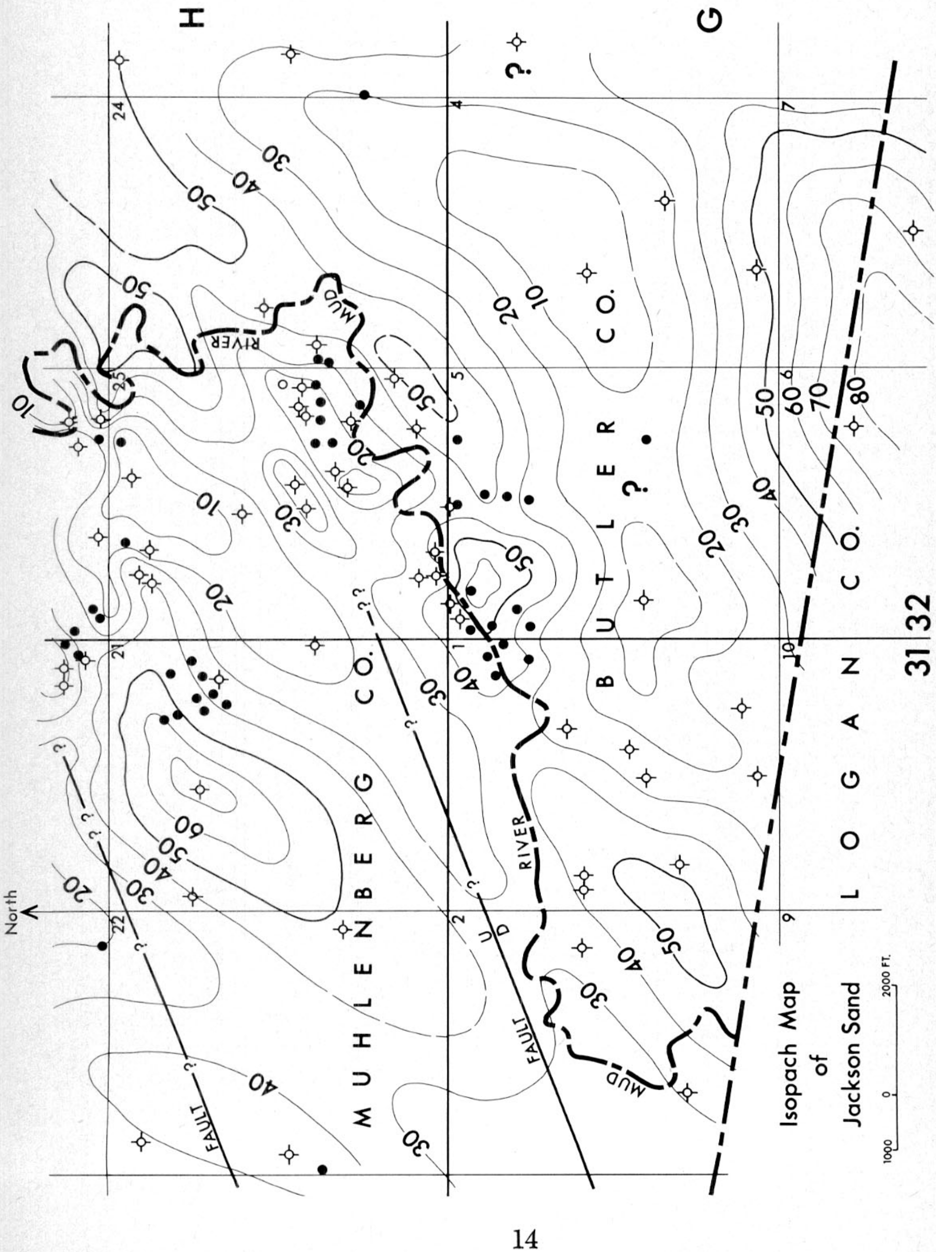

Fig. 4. Isopach map showing thickness of the Jackson sand in the Roundabout pool area. Contour interval is 10 feet.

may produce 100 or more barrels per day; however, within 90 days most such holes are producing about 30 to 40 barrels per day. After one year the five wells on the Gilliam lease are reportedly producing a total of about 60 barrels per day.

FAULTS

The nature of the available records lends itself to many fault interpretations. Some faults do occur; however, there is no evidence of their direct association with local production. The faults shown on the attached structural map are northeast trending, normal, down-to-the-south tension faults quite similar to, and probably a result of, the same forces which cause the much more numerous and complex fault systems north and west of this area. Admittedly, the full extent of the two faults shown on the accompanying maps is unknown; however, if they do continue northeastward there is no evidence of appreciable displacements in this part of southwest Butler County.

FRACTURES

Reportedly, a few wells produce from local fracture zones. These holes are generally quite shallow and in most cases the fractures are in limestones which are overlain by shales and which in turn immediately overlie a nearby productive sandy formation. There is no known history or direct evidence of a consistent association of fracture zones and commercial production in this area.

ECONOMICS

This area has not been carried on current production reports. The best more or less applicable records are assembled and kept by operators involved in secondary recovery operations in the Huntsville pool area 3 to 5 miles northwest of the recent southwestern Butler County play. The entire area, including Huntsville, Mt. Zion, Silver City pools, and the new Roundabout pool, is producing about 30,000 barrels per month. Huntsville pool is primarily Hardinsburg production from an average net pay sand thickness of about 10 feet. The pool covers a little more than 800 acres of proven production from which about 750,000 barrels of primary oil were produced. Secondary recovery analysis figures from several sources indicate estimates of about 100 barrels per acre-foot of recoverable oil; thus, estimates of total recoverable primary and secondary oil from Huntsville pool indicate an expected total of some 1,570,000 barrels of oil from holes averaging about 550 feet in depth. Mt. Zion is a Tar Springs pool 1½ miles southeast of Huntsville and 2½ miles northeast of Roundabout. This pool contains 292 productive acres. The sand averages about 16 feet of net pay section which contains some 159 barrels of oil per acre-foot. Since flooding was initiated almost as soon as the pool was drilled, there is no particular significance to primary and secondary recovery figures; the pool is expected to produce a total of about 731,000 barrels of oil.

With these figures in mind, reasonable total recovery estimates may be assumed for production from these same formations found in geologically similar circumstances at Roundabout. The recently introduced and locally efficient water-fracture completion method may allow a much more rapid rate of primary production; however, total recoverable oil should remain fairly constant.

COMMENTS

This new area should prove economically feasible; however, care must be taken to observe every possible economy of drilling, completion and operation. Completion methods should be carefully considered, particularly since the production interval often displays extreme statigraphic variability. No one method, natural, shooting, water fracturing, or what have you, is universally applicable. Every possible available bit of data must be accurately kept and considered before the one best final completion decision can be made. Operators in this area seem particularly adept at copying the other fellow's mistakes. The use of cores, sample studies, logs, casing and geology are quite haphazard, yet until the recently introduced water-fracture completion methods were worked out by experienced production engineers and competent geologists the area was plagued with 1- to 5-barrel wells. Everyone has his place in this business. There is no economy in the exclusion or omission of competent help from all sources. Neither drillers, geologists, engineers, nor operators know it all.

Careful work by competent people should pay off here sufficiently well to justify much further interest and effort toward the location of similar new pools in this general area.

ACKNOWLEDGEMENTS

The author wishes to gratefully express his appreciation for the assistance extended him in the preparation of this paper. Particular thanks go to Mr. Vladimir Beuk of Quinby & Beuk, Owensboro, Kentucky. Valuable comments and assistance were received from many members of the staffs of Ashland Oil & Refining Co., Producers Pipeline Co., and particularly from many persons on the staff of the Kentucky Geological Survey.

DOES THE OIL AND GAS INDUSTRY NEED DRILLING CONTRACTORS?

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ABSTRACT

This is a frank discussion of mutual problems confronting producers and drilling contractors in the oil and gas industry. The cure to most of the drilling contractors' troubles is fair profit.

Oil and natural gas now accounts for almost three-quarters of the total energy consumed in the United States and will be asked to supply more and more annually. Certainly a large percentage of the increased demands will be acquired by drilling more wells, developing oil and gas reserves here in the United States where it is needed in case of emergency and not depending on foreign sources to supply this most important energy, so essential to our existence. Without it, we cannot survive nor continue to be a major power. The oil and gas industry has two routes to take if it drills more wells:

Number One: Use the drilling contractor.

Number Two: Get in the drilling business themselves.

If it is the operators' intentions to use the Number One route (the drilling contractor), they had better be concerned about the condition the contractor is in at this time or there will only be a small percentage left to do contract drilling—those who did not ignore basic economics, reasonable depreciation, a fair profit on their investment, and a fair wage scale to their rig labor comparative to other industry.

Executives of this most essential oil and gas industry take the attitude, in many instances: "The drilling contractor buys his own razor blades. Why should we be alarmed if he drills on a non-profit basis, or pays his rig labor a less hourly wage than similar high skilled labor in other industry?"

The majority of rotary crews still work a 56-hour week; cable tool crews in most instances still work an 84-hour week.

The *average* hourly wage scale for rotary crews in the Tri-State drilling industry (until very recently) was $2.35 per hour for drillers and $1.80 per hour for drillers' helpers. A small increase has come about recently due to reasons most of the industry in the Tri-State are familiar with, and concerned about. I understand that in the Appalachian area the average wage scale for rotary drillers is $2.92 and drillers' helpers $2.16, with one rotary drilling contractor in that area working a 48-hour week and paying $3.60 per hour for drillers and $2.66 for drillers' helpers. The 48-hour week is gradually being used in Texas, Louisiana, Oklahoma and Kansas, with an hourly wage for drillers of $3.14 and drillers' helpers $2.25.

It's hard to believe, but true; the average hourly wage for cable tool drillers in Eastern Kentucky and West Virginia is $1.35 per hour, and for tool dressers $1.15 per hour. Is this a fair wage scale compared to other industry?

William P. Clements, Jr., President of American Association of Oil Well Drilling Contractors, in a recent talk to the Petroleum Equipment Suppliers Association, stated:

> "The marginal contractor stays in business by selling his rigs to himself. He cannibalizes his rigs and is able to keep barely alive through the cash flow of current business.
>
> "I doubt if they are achieving $200 a day on a $200,000 rig. This is pitiful. And we're looking at another 5 years of the same condition we've had the last 2 or 3 years."
>
> Clements showed the extent to which cannibalizing has taken its toll of the nation's rigs by citing these figures: "Of the 3,400 rigs in the country, about 1,700 are in service today, but only 300 to 500 of the remaining 1,700 are capable of going to work.
>
> "They are not buying from you, the suppliers. They have begged, borrowed, and stolen from the other rigs. However, many contractors have used up their drill pipe and other essential equipment and are now going to supply houses for more—on credit. They are talking to you about credit. And you will put it out in the high-risk area . . . you better watch out. I know what I am talking about. They can't pay you for this necessary equipment—they are not getting enough for their work. The cash isn't there."

Three hundred drilling contractors have gone out of business since 1957. There are 900 in business at this time, trying to survive. It is estimated that 300 more drilling contractors will go out of business in 1962 leaving 600 contractors. Each month we receive, and I suppose every other drilling contractor does, announcements of public auction sales of drilling equipment being sold at ridiculous prices.

This is not a pleasant thought; however, it makes you wonder when your tools will have to be sold under similar conditions. They don't give milk, or like whiskey, improve with age. They only get old, rusty and obsolete—certainly a poor investment. If you think they are not, and you want to see your banker turn into an astronaut, ask him to loan you some money on a rig.

For efficient rig operations, experienced, well trained crews are necessary. The trained crews who formerly operated the drilling rigs have gone to other industry that offer more, not only from a wage standpoint, but a brighter future—at least some sort of a retirement plan, a vacation once a year, and not a layoff the minute the cement plug hits bottom or the well is plugged and abandoned. Certainly there is no incentive for young men to enter the drilling business.

The oil and gas industry desperately needs an improved relationship with the drilling contractor, a better mutual understanding of our common problems. There are too many rigs for the number of wells to be drilled. Experienced rig labor cannot be adequately paid nor retained. Equipment cannot be improved. Research cannot be carried out unless the drilling contractor operates at a reasonable profit. The oil and gas industry has to reduce costs to meet competition, but in reducing these costs they should not expect the reduction to come from lower drilling prices unless there is an offsetting improvement in efficiency. The oil and gas industry cannot use all the rigs available nor can it afford to pay for the contractor's idle rigs. At this point, wisdom is urgently needed. Failure to recognize the real problem and act fairly could hasten the return of those days when the oil and gas industry did their own drilling. Certainly the drilling contractor does not want this to happen as long as he can make a fair profit. If the oil and gas industry returns to drilling their own wells, top management will insist that a fair profit be made on the investment in their newly purchased drilling equipment.

At this point—Number One route, the Drilling Contractor, has been eliminated.

The oil and gas industry elects to take Number Two route—get in the drilling business themselves.

One of the larger producers in the oil and gas industry estimates they will drill 100 wells in the current year ranging in depth from 4,000 to 13,500 feet. They realize that this is a radical departure from what they had done in the past when there were drilling contractors. They also realize that they have no experienced personnel and that it will be necessary to assemble a complete new staff for supervision and rig operation. This may be rather difficult, but by offering top salaries to supervisors and working the crews under their union contract with a 40-hour week, they should be able to locate the necessary men. For the new drilling department, they have prepared a detailed estimate covering investment and first year's operating expenses totaling $6,819,580.00 made up as follows:

10—Complete drilling rigs with all necessary components, pipe, wire line and drill collars, frt. & rig-up	$3,991,000.00
1—Field yard and warehouse with necessary emergency spare parts and equipment	165,000.00
1—Drilling Superintendent	15,000.00
1—Drilling Engineer	12,000.00
1—Assistant Drilling Superintendent	12,000.00
10—Tool Pushers	100,000.00
38—Drillers (40 hour week)	316,160.00
152—Crewmen (40 hour week)	948,420.00
14—Cars and Pickup Trucks	40,000.00
Working Capital	1,000,000.00
Clerical and Auditing Addition	40,000.00
Insurance, Withholding, etc.	150,000.00
Miscellaneous and Contingencies, approx. 4%	30,000.00
TOTAL, FIRST YEAR'S FUNDS	$6,819,580.00

How many companies would like to re-enter the drilling business? What would it do to their drilling costs? "Truth is stranger than fiction." Such a costly day for the oil and gas industry need not arrive. Unwise penny pinching today can be more expense in the future than it was worth.

Certainly there is wisdom enough to be found between the oil and gas industry and the drilling contracting industry to solve our common problems. Actually a six letter word, and it is not doctor, will cure most of the drilling contractors' ailments—fair *profit*.

GAS DEVELOPMENT, PRODUCTION, AND ESTIMATED ULTIMATE RECOVERY OF DEVONIAN SHALE IN EASTERN KENTUCKY

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ABSTRACT

During the past 40 years, 4,713 gas wells producing from the Devonian black shales have been drilled in Eastern Kentucky. At the end of 1961 it is estimated that 1,508,160,000 MCF have been produced from the Devonian shale. The remaining gas reserves of 4,000 Devonian shale wells producing at end of 1961 are estimated to be 400,000,000 MCF, which gives the Devonian shale wells an average estimated ultimate recovery of 405,000 MCF per well. During the past five years, production from the Devonian shale in the Big Sandy gas field has been responsible for more than 70 percent of the total 71 to 73 billion cubic feet produced annually from the entire state of Kentucky.

THE DEVONIAN BLACK SHALE IN EASTERN KENTUCKY

During Devonian time the Cincinnati arch on the west formed slowly out of the geosynclinal trough that was filled with a warm, relatively shallow, epeiric sea. Small low islands were formed west of the present Big Sandy shale fields and were destroyed near the crest of the Cincinnati arch by periodic oscillation of the sea bottom. When the sea deepened over the Appalachian geosyncline, the belt of deposition, rich in organic matter (black shale), contracted westward. To the east, in the deep seas, the light-colored shales were deposited. These shales owe their color to the almost complete absence of either organic material or pyrite. As the sea became shallower, the deposits of rich organic material spread eastward; consequently, the succession of Devonian shales consists of more black rich carbonaceous members in the western localities, well up on the east limb of the Cincinnati arch, than eastward in extreme southeastern Kentucky.

However, to the northwest of the richest gas-producing shale area, higher up on the arch where the black shales are very rich, there is no commercial gas production from the shale.Even deformation, which is responsible for Eastern Kentucky's Paint Creek uplift upon which over 400 feet of rich shale is present, does not produce gas from the black shale in commercial quantities.

The black carbonaceous Devonian shale outcrop in Bath County is less than 200 feet thick; but as the black shale dips to the southeast at a rate of approximately 30 feet per mile, it reaches a thickness of over 400 feet in Magoffin County, 500 to 550 feet through Floyd County, and more than 900 feet in southeastern Pike County. This 900-foot thickness in Pike County includes two or more white "slate"

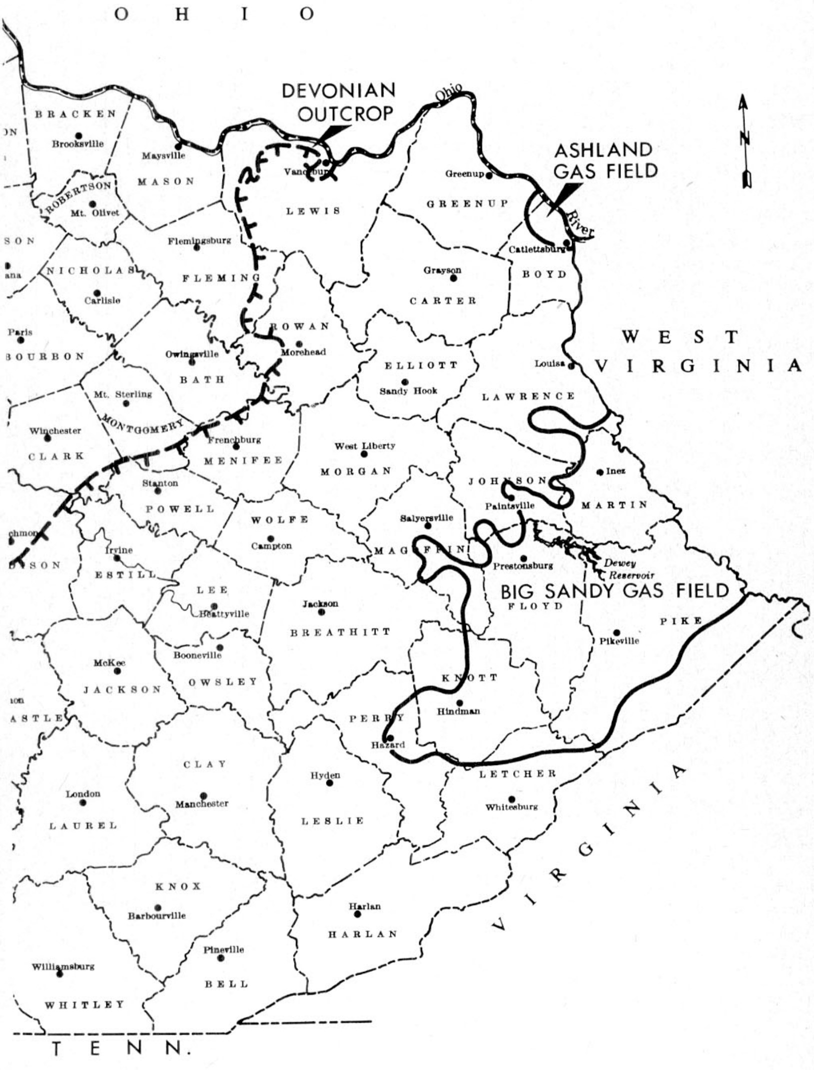

Fig. 1. Map of Eastern Kentucky showing location of Devonian shale gas fields.

breaks which total as much as 300 feet, leaving less than 600 feet of separated rich black shale. The white "slate fingers" extend throughout most of southern Pike County, thin to the northwest, and pinch out in southern Floyd County.

Since the Devonian shales are the most important source of natural gas in Eastern Kentucky, their lithology is important.

To determine the mineral matter in the black Devonian shales, more than 700 thin sections have been made of samples obtained from wells drilled in all areas of Eastern Kentucky. These thin sections are from well samples taken about every 10 feet from the top to the bottom of the shale zone and especially from definite gas-producing zones. To supplement the petrographic identification of mineral matter, quantitative chemical analyses were made on perhaps one-third of these samples.

Studies of these thin sections showed the color of the shale to range from black to brown to greenish-gray. The shale is fissile, very finely laminated, and possesses a hardness of approximately 2.5 on the Mohs's scale. The major constituents are bituminous material, quartz, kaolinite, and pyrite.

The bituminous material contains, in addition to organic fragments, much organic material called "kerogen."

Quartz is by far the most prevalent mineral constituent of the black shale although, in some places, kaolinite is very predominant.

White kaolinite is present in every section. It is generally concealed by the finely divided organic material which seems to be in it. The clay material can best be seen after the kerogen has been removed by a gentle burning of the rock. When this has been done the kaolinite is readily apparent; and even though the kerogen is gone, no visible open space remains in the shale. The clay seems to be the matrix in which the other minerals are embedded.

Pyrite, though common in a variety of forms, is not predominant. The many irregular outlines are due to a filling of interstices.

The minerals vary greatly in percentage throughout the shale although, as a rule, the quartz predominates.

The following average petrographic analyses of black shale from wells in various areas shows the variations in mineral percentage.

Well Location	Percentage				
	Quartz	Bituminous	Pyrite	Total	Kerogen
Right Beaver, Floyd Co.	35.36	47.73	16.91	100	5.14
Right Beaver, Floyd Co.	40.46	49.16	10.38	100	3.68
Mud Creek, Floyd County	49.78	36.75	13.47	100	3.36
Eastern Pike County	60.75	34.35	4.90	100	2.75
Knox County (no gas)	46.80	49.40	3.80	100	3.80
Dry Fork, Knott County	34.44	58.56	7.00	100	1.77

Crouse* has analyzed the shale of four localities and found the average contents as follows:

Constituent	Percentage
Volatile Matter	18.47
Silica	45.40
Alumina	19.86
Ferric Oxide	7.96
Potassium Oxide	2.64
Other Minerals	5.27
Total	100.00

DEVELOPMENT

In Eastern Kentucky a total of 7,203 wells have been drilled for gas in the Ashland gas field of Boyd County and in the Big Sandy gas field of Floyd, Martin, Knott, Pike, and small adjoining areas of Lawrence, Johnson, Magoffin, Perry, and Letcher Counties, Kentucky.

Of the 7,203 wells drilled, 4,205 were completed as Devonian black shale gas wells, developing a total open flow of 1,450,220 MCF, or an average of 342 MCF per well (table 1). Of the remaining 2,898 wells, 1,967 developed 2,894,146 MCF and averaged 1,471 MCF per well from other gas-producing horizons above and below the Devonian shale; and 931 wells, or 13 percent, were dry holes.

TABLE 1. DEVONIAN SHALE DEVELOPMENT IN EASTERN KENTUCKY AS OF DECEMBER 31, 1961

	Devonian Shale			Other Producing Formations*			
		Open Flow			Open Flow		
County	No. Wells	Total MCF	Average MCF	No. Wells	Total MCF	Average MCF	Dry Holes
Big Sandy:							
Floyd	1,216	554,973	489	503	677,699	1,341	171
Martin	476	167,930	360	258	324,109	1,257	96
Knott	788	219,942	266	125	134,390	1,075	93
Pike	1,295	400,687	309	543	1,206,676	2,222	227
Magoffin	33	10,403	315	336	495,545	1,475	178
Johnson	46	6,746	147	67	23,875	356	44
Letcher	63	6,866	109	8	5,336	667	24
Perry	70	11,000	157	10	8,777	878	11
Lawrence	30	8,667	289	112	15,564	139	47
TOTAL	4,008	1,387,214	346	1,962	2,891,971	1,474	891
Boyd	197	63,006	320	5	2,175	435	40
TOTAL ALL	4,205	1,450,220	342	1,967	2,894,146	1,471	931

* Salt Sand, Maxon, Big Lime, Big Injun, Weir, Berea, Corniferous, and Big 6.

* Crouse, C. S., 1925, An economic study of the black Devonian shales of Kentucky: Kentucky Geol. Survey, ser. VI, vol. 21, p. 59-97.

Knott County has the greatest percentage of gas wells producing from the Devonian shale, 78.3 percent (table 2), with only 9.2 percent of the drilled wells being dry, while Magoffin County has the greatest percentage of dry holes, 32.5 percent, with only 6.3 percent of its wells producing from the Devonian shale.

TABLE 2. BIG SANDY GAS FIELD SHOWING PERCENTAGE GAS WELLS BY PRODUCING FORMATIONS AND DRY HOLES

County	Salt Sand	Maxon	Big Lime Berea	Devonian Shale	Corniferous Big 6	Dry Holes	Total Wells Drilled
Floyd	7.1	10.6	8.0 B.L.	64.3	1.0	9.0	1,890
Martin	9.6	12.8	8.3 B.L.	56.9	0.7	11.7	821
Knott	1.5	4.2	6.8 B.L.	78.3	0	9.2	1,006
Pike	2.7	10.2	Ber. 13.3 B.L.	62.7	0.1	11.0	2,065
Magoffin	21.9	8.2	Ber. 10.7 B.L.	6.3	20.4 B-6	32.5	547
Johnson	1.9	1.9	7.0 B.L.	29.3	31.8 B-6	28.1	157
Letcher	3.1	2.1	3.1 B.L.	66.3	0	25.4	95
Perry	2.2	0	8.8 B.L.	76.9	0	12.1	91
Lawrence	0	0	49.7 Ber.	15.9	9.5 Cor.	24.9	189
TOTAL	5.9	8.9	10.7	58.5	3.0	13.0	6,861

Table 1 shows that, in the Big Sandy gas field, 58.5 percent of the gas wells were producing from the Devonian shale in 1961 but that these had developed only 32.4 percent of the total open flow of 4,279,185 MCF.

In addition to the original 4,205 Devonian shale-producing completions, 29 percent of the shallower-than-shale were deepened to productive shale wells after depletion of their shallow production.

In the Ashland field, 97.5 percent of the wells drilled produced from the shale while, in the Big Sandy field, 508 of the 1,754 shallower-than-shale wells were deepened to shale.

The greatest factor responsible for commercial gas production from the Devonian shale is the shooting of the 500 to 700 feet of black shale with from 4,000 to 9,000 pounds of gelatinated nitroglycerin. Statistics in table 3 show that only 4.8 percent of Devonian shale wells drilled were large natural producers, with an average open flow of 1,117 MCF, and did not require shooting. The remaining 95.2 percent of the 4,713 shale and deepened-to-shale gas wells had an average open flow of only 53 MCF before shot, and 40.5 percent of these wells had no measurable gas before shot. After shot, their average open flow was 253 MCF and only 10.5 percent were dry holes.

PRODUCTION

For the past five years Kentucky has produced from 71 to 73 billion cubic feet of gas annually. The most consistent production from year to year comes from the Big Sandy gas field which annually accounts for 90 percent of the total gas produced in the State.

According to actual production figures on 39 percent of the wells in the Big Sandy field, it is estimated that the 6,172 producing Wells in the Ashland and Big Sandy gas fields have produced 1 trillion, 975 billion cubic feet. Of this total, the 4,713 Devonian shale gas wells have produced 76 percent, or 1 trillion, 508 billion, 160 million cubic feet.

Production from the shale varies greatly, not only from one area to another but between offset wells. This is because there are two orders of magnitude, or porous and permeable systems, that constitute the primary and secondary shale gas reservoirs. The primary reservoirs consist of silty and sandy zones in the shale with porosity and permeability controlled by grain size, shape, sorting, and degree of cementation. The silty or sandy zones are exceedingly fine-grained and tight—certainly too low in effective porosity to permit gas accumulation in commercial amounts.

TABLE 3. RESPONSE OF SHALE WELLS TO SHOOTING

	Natural Shale Wells Not Shot		Wells Shot			After Shot	
County	%	Avg. O. F. MCF	%	Average Open Flow Before Shot MCF	Average Open Flow After Shot MCF	% Wells Less 100 MCF	% Wells Dry Holes
Floyd	9.7	817	90.3	68	360	24.9	8.3
Martin	4.2	1,072	95.8	46	269	31.8	8.2
Knott	2.2	975	97.8	58	238	31.5	7.5
Pike	3.4	1,955	96.6	48	201	36.6	11.7
Magoffin ..	0.1	700	99.9	26	151	60.6	40.8
Johnson	0	0	100.0	21	105	51.5	26.5
Perry	0	0	100.0	37	133	31.3	15.6
Letcher	0	0	100.0	12	86	67.8	23.8
TOTAL	4.8	1,117	95.2	53	253	32.8	10.5

Of the 95.2% Shale wells shot 40.0% had no measurable open flow before shot.

The secondary reservoirs are controlled by vertical joints and fractures and, to a less extent, the bedding planes. It is into these secondary reservoirs that the greatest percentage (92.2 percent) of shale wells are shot. Rather uniform rock-pressure decline throughout the producing area indicates a type of permeable system that would be afforded by joints and fractures rather than by silty zones of low porosity and permeability. When shale wells in the field are shut-in for a fairly long period, there is a uniform pressure recovery, even to the extent indicative of gas seepage from the silty reservoirs of low permeability to the more highly permeable joint systems.

Figure 2 is a good illustration of the great variations in shale development, production, and estimated ultimate recovery. The wells are located in the richest shale-producing area of the Big Sandy gas field on Left Beaver Creek in Floyd County. As shown in the west-east cross section, Well No. 545 had a natural open flow of 2,558

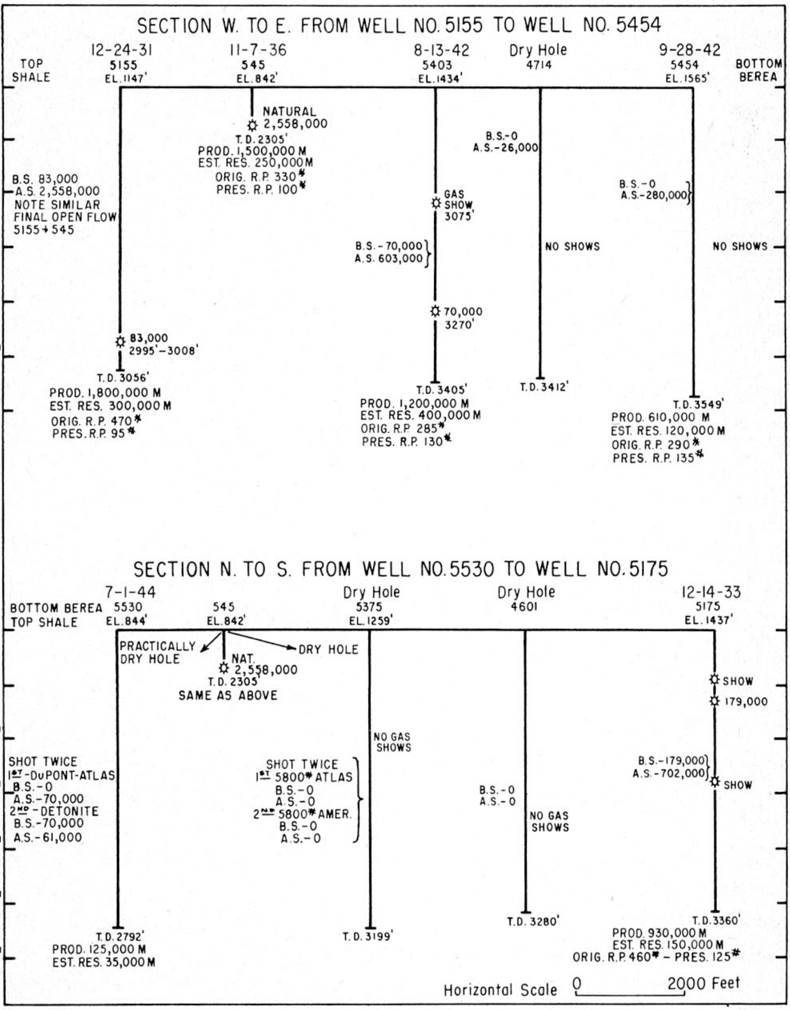

Fig. 2. Cross sections showing variation in gas production from Devonian shale.

MCF (encountered 100 feet into the shale) while in an offset well (1,900 feet to the west) only 83 MCF was encountered at a depth of 500 feet into the shale; after shot this well had an open flow of 2,258 MCF. Well No. 5155 was completed in 1931 with an original rock pressure of 470 pounds and, as of the end of 1961, had produced 1,800,000 MCF, while Well No. 545 (drilled five years later) had an original rock pressure of 330 pounds and at the end of 1961 had produced 1,500,000 MCF. The present rock pressure of both wells is approximately 100 pounds. Had Well No. 545 been completed the same year as Well No. 5155, their original rock pressures would have been nearly equal and both would have produced approximately the same amount of gas. Well No. 5403 (more than 2,000 feet east of Well No. 545 and completed in 1942) had an original open flow of 603 MCF after shot and a rock pressure of 285 pounds. This well has produced 1,200,000 MCF and has a remaining rock pressure of 130 pounds, 30 pounds greater than Well No. 545.

As shown in the north-south cross section, Figure 2, offset Well No. 5530 to the north of Well No. 545 had an open flow of only 61 MCF after shot, while offset Well No. 5375 to the south of Well No. 545 was a dry hole after being shot twice. Certainly, neither of these wells was shot into any of the secondary reservoirs which account for the rich production of the area.

Well No. 4714 had no gas show, and only 23 MCF after shot (dry hole).

Well No. 5454, an offset to Well No. 4714, had no gas show before shot. After shot it flowed 280 MCF and has produced 610,000 MCF in 20 years.

Well No. 4601 had no gas show even after shot.

ESTIMATED ULTIMATE RECOVERY FROM DEVELOPED DEVONIAN SHALE AREAS

Estimated ultimate recovery from the developed Devonian shale areas in Eastern Kentucky is the total of gas produced plus an estimate of the gas to be produced from remaining wells, to depletion.

The estimate of remaining shale gas to be produced is based on production records of 1,595 shale wells, and pressure-decline graphs which show the annual and cumulative production as of December 31, 1961, extended to depletion at 60 psia. These graphs, for both large and small shale wells, are described in the Bulletin of the American Association of Petroleum Geologists, vol. 37, no. 2, February 1953, p. 282-299. According to these graphs, the 1,595 shale wells have an average remaining receovery of approximately 100,000 MCF per well.

Of the 4,713 original new and deepened shale wells, 566 have been abandoned and 147 are so near depletion that the remaining reserves are negligible. The remaining 4,000 producing shale wells have an estimated recoverable reserve of 400,000,000 MCF.

Estimated Ultimate Shale Recovery:

Production through Dec., 1961, from 4,713 shale wells	1,508,600,000 MCF
Estimated remaining reserves from 4,000 shale wells	400,000,000 MCF
Total estimated ultimate recovery	1,908,600,000 MCF
Average shale recovery per well	405,000 MCF

The great difference in the ultimate shale gas recovery from one well to another, from one area to another, is further shown by the estimated ultimate recovery per well, by county, as established by accurate production data from 33 percent of shale wells drilled in the Big Sandy gas field:

County	Estimated Ultimate Recovery Per Well
Floyd	550,000 MCF
Knott	400,000 MCF
Pike	325,000 MCF
Martin	260,000 MCF
Perry	205,000 MCF
Johnson	150,000 MCF

In this paper no attempt has been made to estimate the remaining recoverable reserves in shallow and deeper-than-shale producing wells. No attempt is made to estimate the future proven gas reserves from all gas horizons in Eastern Kentucky; however, the the American Gas Association has estimated there are, as of December 31, 1961, a total of 1,126,788,000 MCF of proven gas reserves in the state of Kentucky. Their report estimates that more than 32 percent of these reserves will be produced from 4,000 Devonian shale wells now producing in the Big Sandy gas field.

Future development for gas in Eastern Kentucky, especially for production from the Devonian shale, is entirely a matter of economics.

RECENT DEVELOPMENTS IN WELL COMPLETIONS

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ABSTRACT

Advanced methods in cementing techniques, hydraulic penetration of casing and formation, new cleanout agents, and use of hydraulic fracturing and propping agents enable the owners of oil and gas wells to plan a more scientific and successful operation.

INTRODUCTION

Many new and improved oil and gas well completion techniques have evolved from the laboratories of well-service companies. A continuing effort will be made by their research and development laboratories to improve present methods, materials, and equipment and find new and better techniques for oil and gas well completion.

CASING CEMENTING TOOLS AND TECHNIQUES

Problems such as encountered in Kentucky have led to the development of a multiple stage "DV" Packer Cementing Collar. This tool permits placement of the first stage of cement around the bottom of the casing while allowing the second stage to be placed a great distance up the hole from the top of the first. A rubber packer immediately below the top stage tends to support that column and isolate the two cement stages. It is very helpful in placing cement above a lost-circulation zone, or placing cement between a high pressure section and a lost-circulation zone.

Materials also have been developed to aid in primary and squeeze cementing. Low-fluid-loss materials, that tend to prevent rapid dehydration of the cement slurry, allow longer pumping or displacement time. This, in turn, contributes to better placement of cement slurry during the primary operation. Low-fluid-loss materials also tend to permit more efficient squeeze work by reducing premature dehydration of the slurry in the tubing or casing. Squeeze pressures are reduced considerably in many instances.

There is a definite interest pertaining to better primary cementing operations. Drilling mud, although a very important factor in drilling many wells, can sometimes be the cause of a poor primary cementing job. The need for removal of the mud from the pipe, and filter cake from the face of the formation, has contributed to the development of chemical mud cleaning solutions, as well as mechanical cleaners. Research has indicated that annular plug flow may remove approximately 60 percent of the circulatable mud; laminar flow, 90 percent; and turbulent flow, 95 percent.

Since different cement compositions (Non-Newtonian Fluid) require various rates, greater than that of water or chemical washes, to remove the mud, a system using an electronic computer with information pertaining to the mud and specific cementing composition fed to it, will calculate:

1. Estimated minimum rate necessary for cement to attain turbulent flow.
2. Estimated pressures expected at the well head for each 200 feet, as the top plug and cement slurry are pumped down until they are in place.
3. Estimated hydraulic horsepower necessary to accomplish numbers 1 and 2.
4. Selection of cementing composition using various additives, which would tend to achieve turbulent flow at lower rates, thereby reducing necessary horsepower requirements.

More frequent slim hole completions have inspired the development of a complete line of floating equipment, tools, etc., for 2 ⅞-inch O. D. tubing and larger.

HYDRAULIC PENETRATION OF CASING AND FORMATION

In addition to jet and bullet perforating, another device for casing and open hole penetration, or notching, is the hydraulic jetting tool. Sand, mixed with oil or water, is focused through a jet at the casing or open hole. The velocity and pressure of these can erode away casing or formation creating a slot (horizontal or vertical), or perforations. These tools are available for all casing sizes. The removable hydraulic jetting tool has been very well accepted in the East. This tool may permit notching or perforating and then removal of the tool to replace jets, acidize, fracture, or produce without tripping the tubing. It utilizes a seating nipple to allow placement of a pump, again without tripping the tubing. The jet tool may be removed by reverse circulation or wire line.

The hydraulic jetting tool has aided greatly in many cases to lower breakdown and treating pressures in well-stimulation operations. In the absence of a mechanical casing cutter it will also serve as a notching tool for the Single-Point-Entry method of hydraulic fracturing. Other uses for the tool are: under-reaming, cutting pipe for removal, removing scale or debris from pipe or formation, and washing down holes.

CLEANING AGENTS PRIOR TO WELL STIMULATION

Mud Cleanout Agents have proven to lower breakdown and treating pressures in many cases. Other new perforating fluids have been developed which may be placed behind the top cementing plug, thereby reducing the need for swabbing the casing to place acid on bottom prior to or following perforating. Utilizing different materials, these new perforating fluids cause a minimum of corrosion over extended periods of time.

HYDRAULIC FRACTURING ADVANCEMENTS

Hydraulic fracturing is no longer necessarily a hit and miss proposition. New, advanced methods are available to aid the well owner in planning a more scientific and successful fracturing operation.

One new method utilizes cores of the formation to be fractured, along with a sample of the formation fluid and the fluid to be used in the stimulation operation. These are tested under simulated well conditions. From evaluation of these tests, the most compatible and efficient fluid is determined, the propping agents are tested as to their fracture flow capacities, and the fracture area, or volume of fluid, is calculated. Using this method, the service company is better able to present the well owner with more specific recommendations for his consideration and final selection.

Some pertinent information, taken from one of these analyses of a sand in Kentucky, follows:

SAND
Kentucky

Propping Agent	(lbs/gal—Cp Max) Sand Concentration	Percent Crushed	Calculated (md-ft) Flow Capacity
20/40 round sand	.59	2.2	3618
20/40 round sand	1.12	.9	803
20/40 angular sand	.69	14.3	2595
20/40 angular sand	1.12	4.1	639
12/20 walnut hulls	.2	0	69802
8/12 walnut hulls	.2	0	82098
12/16 walnut hulls	.2	0	100000
10/20 round sand	1.21	8.7	11410

Core Analysis

Porosity	Permeability (md) Horiz.	Vert.	Solubility	Salt Content mg/100 gm core
18.9	1.9	1.7	18.5	380
18.5	2.2	2.4	3.0	350
18.2	1.9	1.9	4.3	340
16.3	.5	.4	5.2	260
9.2	<1	<1	13.0	340
17.2	.8	.47	5.0	310

No noticeable undesirable effects were realized when the core was immersed in H_2O or oil, but a small amount of fines resulted from immersion of some of the core in acid.

Additive	*Fluid Efficiency*
0 – WAC-8 2 lbs./1000 gal H_2O – FR-2	0.0102 (E_w)
10 lbs./1000 gal H_2O – WAC-8 2 lbs./1000 gal H_2O – FR-2	0.0017 (E_w)
25 lbs./1000 gal H_2O – WAC-8 2 lbs./1000 gal H_2O – FR-2	0.00168 (E_w)
50 lbs./1000 gal H_2O – WAC-8 2 lbs./1000 gal H_2O – FR-2	0.00126 (E_w)

Rate (bbl/min)	*Area* (sq. ft.)	*Total Volume* (gal)	*Additive–* lbs./1000 gal fresh H_2O	E_w
20	8,900	13,543	0–WAC-8	
40	12,118	13,593	0– "	0.0102
20	8,900	2,172	10– "	
40	12,100	2,707	10– "	
20	34,292	13,569	10– "	
40	41,378	13,571	10– "	0.0017
20	50,000	22,995	10– "	
40	50,000	16,971	10– "	
20	8,900	1,913	50– "	
40	12,100	2,451	50– "	0.00126
20	34,300	10,490	50– "	
40	41,400	10,791	50– "	
20	18,000	4,516	50– "	
40	18,000	3,877	50– "	
20	50,000	17,616	50– "	
40	50,000	13,781	50– "	

NEW DEVELOPMENTS IN APPALACHIAN LOGGING SERVICES

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ABSTRACT

New developments in logging methods in the Appalachian Region make it possible to obtain accurate quantitative analyses of formations under empty-hole conditions. With the addition of the Formation Density Log, which accurately measures porosity in both empty and fluid-filled holes, a complete logging program has been made available for cable tool drilling conditions. This program includes the Formation Density Log, the Gamma Ray-Neutron Log and the Induction Log. With these logs, porosity, and gas, oil, and water saturations can be calculated.

Another development which has proven to be a valuable addition to logging methods is the Cement Bond Log. This service has made possible an extensive examination of the cement surrounding the casing in a bore hole.

With these recent improvements in logging methods, the operator can more completely evaluate his well, and, in turn, operate more efficiently and economically.

For a number of years the oil and gas industry has used logging methods which make possible accurate quantitative analyses of formations. These methods of logging have been dependent upon a fluid column in the bore hole and were designed to operate under a variety of fluid conditions. Until recently, in the Appalachian region, quantitative analysis was not possible due to the lack of an accurate porosity measuring tool for empty-hole logging. In the past two years such a tool has been developed and proven by extensive field testing. It is called the Formation Density tool. With the innovation of the Formation Density Log, a complete logging program was made available for empty-hole conditions.

The recommended basic logging program for such empty wells includes, in addition to the Formation Density Log, an Induction Log and a Gamma Ray-Neutron Log. A comparison of Density and Neutron responses permits the determination of both porosity and gas saturation. The Induction Log is then used to analyze the liquid saturation; discrimination between oil and water, and definition of the relative amounts of each are accomplished. This program thus provides the data necessary to compute porosity, and gas, oil, and water saturations.

Simultaneously with the recording of the Formation Density Log, a Caliper curve is recorded. This information on hole diameter is of value in both the interpretation of the logs and in the planning of the well completion.

The Gamma Ray curve is used to define shale content of the formations. Thus, through the use of the Gamma Ray, and the Density and Neutron responses, the lithology of the formations is described. Such definition enables correlation from well to well—and even from field to field in most instances.

In addition to the logs of the basic program, the Temperature Survey is frequently used to detect the entry of gas into the borehole. Measurement of the temperature anomaly also permits a quantitative evaluation of the rate of gas flow from the formation (Kunz, 1955). Such rate of flow normally will be less than that to be expected following well completion and stimulation.

The efficiency of the recently introduced logging program, bolstered by the older services, has led to greatly increased logging activity in the cable tool wells of the Appalachian area. These newer methods have greatly reduced the possibilities of abandoning a commercially productive well or of attempting a completion on a dry hole.

Another development which was introduced several years ago is the Cement Bond Log. The logging method involves the use of a sonic-type tool which emits and measures a sound pulse transmitted by the casing (Grosmangin, 1960). The decrease in energy as the pulse travels from the sound source to a receiver can be related to the effectiveness of the cementing operation in isolating productive zones. Continuous research and development tests have shown a definite relationship between compressive strengths of cement and the sonic amplitude readings recorded by the Cement Bond Log.

With the Cement Bond Log the production engineer can:

1. Locate cement tops.
2. Determine possible communication or channeling.
3. Evaluate the effectiveness of squeeze operations.
4. Locate the casing-free point.
5. Compare studies of various completion practices.

Thus, to the benefits derived from logging evaluation of wells, the Cenment Bond Log has provided a means of improving and insuring effective completions.

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THE DETERMINATION OF THE BONDING QUALITY OF CEMENT TO CASING

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ABSTRACT

An acoustic device known as the Cement Bond Logging Tool, a comparatively new wire line service for oil field use, has been introduced for the purpose of providing information on the quality and effectiveness of the cement bond behind the casing. While other instruments in use locate the top of the cement column, the Cement Bond log indicates where the cement is bonded to the pipe and the nature of the bonding. Both principle and application of the device are explained and a case history reported.

This paper describes the principles involved in using an acoustic device to determine the quality of bonding between cement and casing. Practical applications of cement bond logging are presented with results obtained from field usage.

A comparatively new wire-line service, the Cement Bond log was designed and introduced to the field to give oil and gas people information concerning the quality of a cement job at a given depth, as well as the effective top of the cement behind the pipe. As you are well aware, we have other tools which will locate the top of a column of cement; for example, the Temperature log, the Nuclear Cement Top Locator, and the Radioactive Tracer logs (fig. 1).

The Cement Bond log works on the principle that the amplitude (signal strength) of a sound signal traveling in a pipe is greatly reduced where the cement is well bonded to the pipe—compared to what it would be if the cement were not bonded or poorly bonded. This variation in the amplitude of the sound signal is the parameter measured in determining whether or not the cement is bonded to the pipe.

The reason for the reduction of amplitude in a well bonded pipe is simple; the sound wave momentarily deforms the casing wall as it travels through the casing. Part of this deformation is longitudinal (vertical in the case of pipe in a bore hole) and anything solid and bonded to the casing will be carried along with the pipe during deformation. The velocity of sound in the pipe is at least two times its velocity in the cement; therefore, there is a continuous transfer of energy from the wave front in the casing to the wave front in the cement. This results in a considerable loss in signal energy where

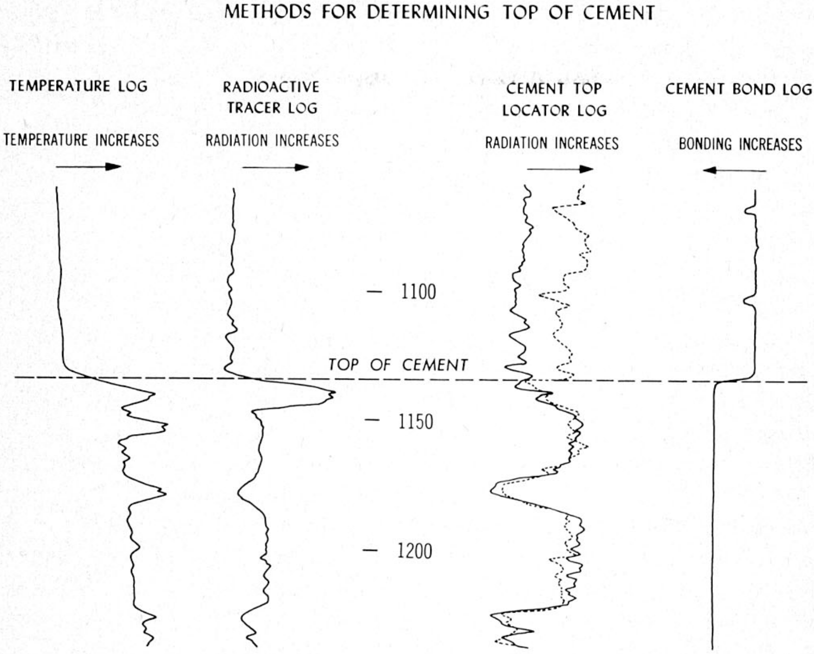

Fig. 1. Methods for determining top of cement behind casing.

the cement is well bonded to the casing. In those places where cement is present, but not bonded to the casing, the log is essentially the same as would be recorded opposite a zone where no cement was present behind the pipe.

The present-day demands of well-stimulation methods for higher injection rates, heavier sand concentrations and wide ranges of treating pressures have made the proper bonding of cement more important than ever before. It seems reasonable to assume with the present knowledge about the different conditions of the bonding qualities of cement found in numerous wells, that what was once considered to be an unsuccessful treatment of a zone could very well have been caused by loss of the treating fluids via unbonded portions of the hole. It is not the intentions of the writer to imply that every unsuccessful stimulation treatment is the result of poorly bonded cement. However, considerably more importance should be given to this part of the completion practice than has been given in the past.

Cementing problems vary from area to area and sometimes from well to well within the same geological sections. The Cement Bond log has been of great value to both the cementing companies and the operators in developing specific techniques and admixtures for problem wells. One such area is in and around Gilbert, West Virginia, where considerable trouble has occurred not only in obtaining good bond, but sufficient fill-up of cement behind the pipe (fig. 2).

The Gilbert Creek Gas Company recently cemented approximately 3,300 feet of 4½-inch, 9.5-pound pipe through the Berea Sand in this area and it was one of the most successful cementing operations ever observed by the writer. This operation was performed in two stages with the stage tool at a depth of 2,775 feet, approximately 525 feet above the lower pay zone. This interval is composed mostly of shale. The upper pay zone was at a depth of 2,665 feet. The down-hole equipment consisted of a guide shoe, float collar, Halliburton Stage Tool, 2 Baker wire baskets and 8 centralizers. Four hundred barrels of mud was mixed and used to establish and re-establish circulation. Each 100 barrels contained 4 sacks of Aquagel, 1 ½ sacks of cotton seed hulls, 1 sack of Jel-Flake and 1 sack of Driscose. Circulation was established and then shut down for 30 minutes. Circulation was re-established with 6 additional barrels of mud and again shut down for 30 minutes. Circulation was again re-established with 1 additional barrel of mud. The first stage was

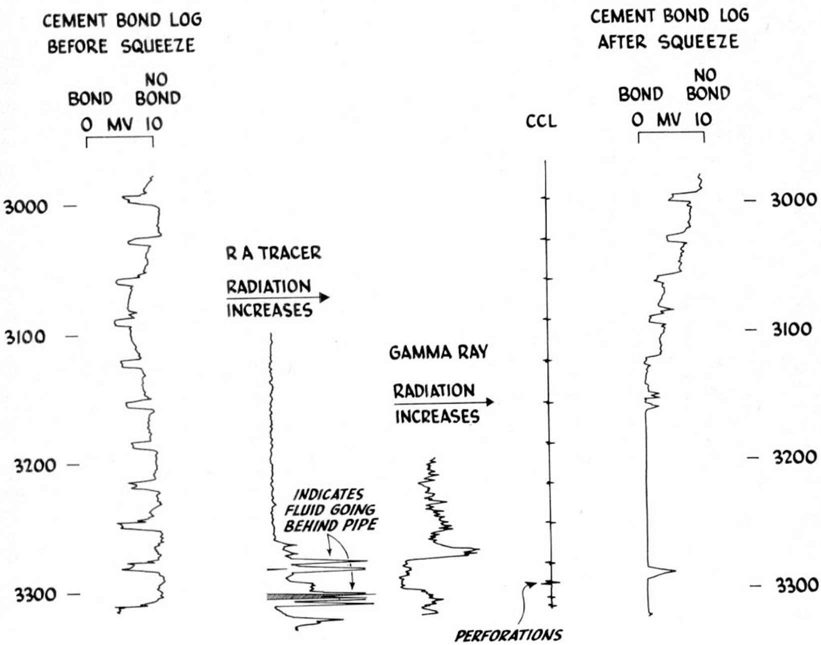

Fig. 2. Logs showing effectiveness of cement bond.

cemented with 110 sacks of 50-50 Litepoz No. 2 with 2 percent accelerator. This was pumped at the rate of 11 barrels per minute. The float collar was set and the well was shut-in for 4 hours before re-establishing circulation with 4 barrels of additional mud. The second stage was then cemented with 120 sacks of 50-50 Litepoz No. 2 with 3 percent accelerator. This was again displaced at the rate of 11 barrels per minute. A Cement Bond log was then run after 40 hours of shut-in time to determine the quality of the bond to the pipe. The log showed no bonding from 3,310 to 3,805, good bonding from 2,788 to 2,144, and partial bonding from 2,789 to 2,798. The lower zone was squeezed with 50 sacks of Flac cement at approximately 300 psi. The well was shut-in for 18 hours and another Cement Bond log was run which showed good bonding from 3,315 to 3,294 and from 3,285 to 3,161. Partial bonding was evident from 3,294 to 3,285.

In conclusion, in areas where considerable cementing difficulties have occurred, it is suggested that particular attention be given to the cementing phase of the completion program. Field experiences have confirmed that poorly bonded pipe will result in partial or complete loss of the injected fluids.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Birdwell Division of Seismograph Service Corporation for permission to present this paper and to the Gilbert Creek Gas Company for permission to use their log and cementing information. Also to Dr. E. James Moore for his criticism and review and the Birdwell employees for their valuable assistance.

OIL PRODUCTION IN KENTUCKY FOR YEAR 1961

Compiled by Kentucky Geological Survey, Lexington, Kentucky

County	*Barrels*	*County*	*Barrels*
Adair	18,707	Lawrence	362,396
Allen	92,584	Lee	1,522,846
Barren	78,347	Leslie	4,707
Bath	5,594	Letcher	12,035
Bell	786	Lincoln	16,209
Boyd	714	Logan	1,331
Breathitt	181,035	McCreary	1,141
Breckinridge	204,205	McLean	696,587
Butler	362,565	Magoffin	1,094,355
Casey	23,925	Martin	20,714
Christian	1,312,857	Metcalfe	224,419
Clinton	180,422	Monroe	1,079
Crittenden	89	Morgan	1,236
Cumberland	47,740	Muhlenberg	773,264
Daviess	1,643,159	Ohio	981,708
Edmonson	1,481	Owsley	1,433
Elliott	79,232	Perry	4,682
Estill	117,937	Pike	55,355
Floyd	27,674	Powell	241,350
Green	962,909	Rockcastle	38
Greenup	216	Russell	10,583
Hancock	320,616	Simpson	9,705
Hardin	1,120	Taylor	248,240
Hart	58,411	Todd	10,070
Henderson	3,334,888	Union	1,660,691
Hopkins	58,382	Warren	40,657
Jackson	1,242	Wayne	44,536
Johnson	153,051	Webster	941,597
Kenton	1,122	Whitley	38,836
Knott	17,012	Wolfe	29,676
Knox	3,322		
Laurel	1,417	TOTAL	18,344,237

THE BON HARBOR GAS POOL, DAVIESS COUNTY, KENTUCKY — A WALTERSBURG ANOMALY

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ABSTRACT

This paper is primarily a discussion of the discovery and geology of the Bon Harbor Gas pool and is illustrated graphically by the following:

1. Structure map on base of the Lower Menard limestone.
2. Isopach map showing a thinning interval between a shallow limestone and the base of the Lower Menard limestone.
3. An east-west cross section across the pool.
4. Electric logs of productive and non-productive wells.

The word "anomaly" was used in the title because to the writer's knowledge this is the only commercial gas pool in the Waltersburg sand in Indiana and Kentucky. The type of trap for this pool is considered to be stratigraphic rather than structural and the Waltersburg sandstone was probably deposited as an off-shore sand bar.

A brief discussion of the area relating to the formation of gas, production, and reserves is also presented.

INTRODUCTION

Geographically this gas area is located in Section 11-P-28, Daviess County, Kentucky, approximately two miles northwest of Owensboro, Kentucky.

Geologically, the Bon Harbor Gas pool is located in the east-central Kentucky lobe of the Eastern Interior coal basin. It is approximately fifteen miles north of the main Rough Creek fault system and would be classified as being in the shallow shelf area of the basin. This area is affected by faulting which trends generally northeast-southwest. These faults are probably relief tension faults originating from the Rough Creek faulting to the south. Regional strike is generally north with an average regional dip of thirty-five feet to the mile in a westerly direction.

I will not discuss in detail the complete stratigraphy of this area in the main part of the paper as the usual succession of formations of the Pennsylvanian and Mississippian systems is present in this area.

Some of you may wonder about the use of the word "anomaly" in this title. Actually, there are several minor "anomalies" in this area, but the most important to my knowledge is that this is the only commercial gas pool from the Waltersburg sand in the states of Indiana and Kentucky. Normally, the Waltersburg produces gas associated with oil or the sand is water bearing.

This gas area was primarily a Waltersburg prospect and was drilled with the hope of finding a commercial oil pool. Drilling this prospect—whether for oil or gas—was based on what I consider the primary qualifications for "a Class A" prospect:

1. At least one type of trap.
2. Good reservoir conditions.
3. Presence of hydrocarbons in surrounding area.

These conditions, which the leased area seemed to meet, were determined by four dry holes in the general area. Further supplementing this information were several core holes to a shallow limestone marker. An isopach map between the shallow limestone and the base of the Lower Menard limestone showed a very definite thinning (fig. 2) across the area. This thinning was interpreted as being the result of a build-up of the Waltersburg sandstone. The result of the drilling and development of the area and the present interpreta-

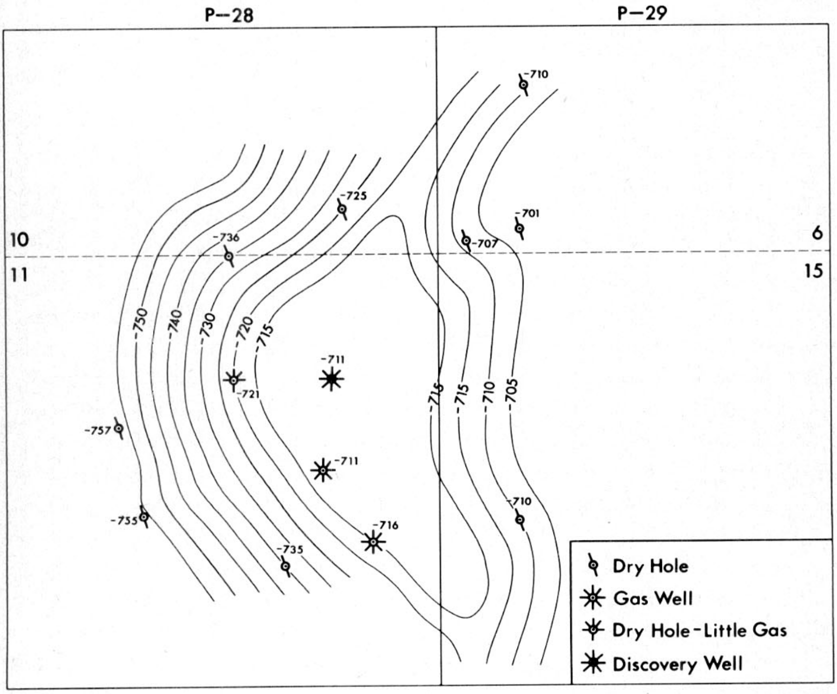

Fig. 1. Structure map of Bon Harbor Gas pool with contours on base of Lower Menard limestone. Contour interval is five feet.

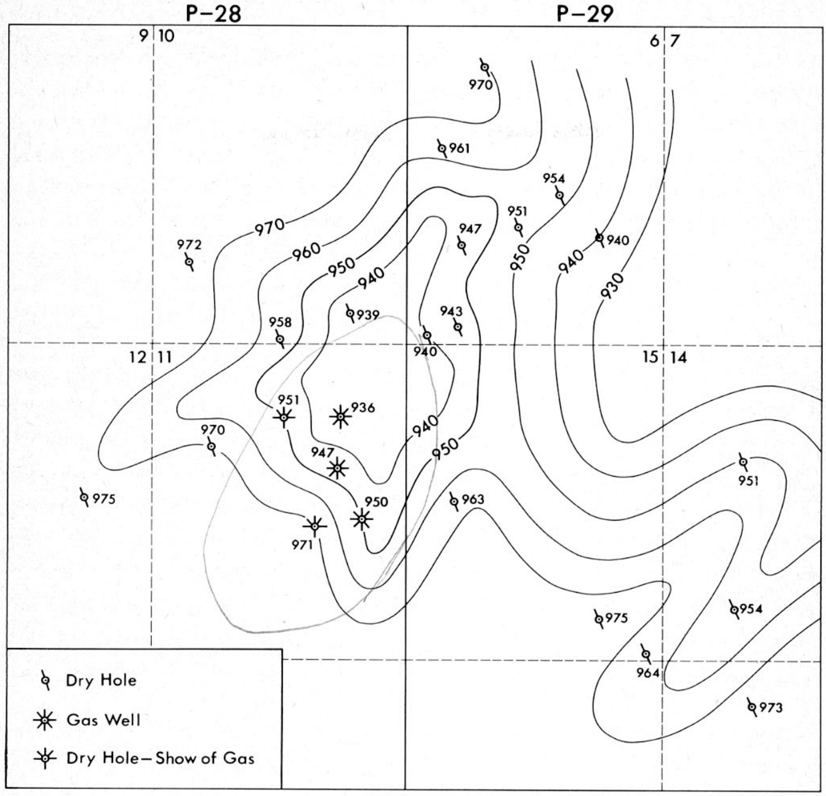

Fig. 2. Isopach map of Bon Harbor Gas pool area showing interval between a shallow Pennsylvanian limestone and base of Lower Menard limestone. Isopach interval is 10 feet.

tion of the geoglogical conditions will be shown in the following discussion.

DISCOVERY AND HISTORY

This gas area was discovered on October 25, 1962, by Jack Cox and Marhill Oil and Gas Co. Some of you may recall seeing an article in the Courier-Journal describing the discovery well. The sand was topped at 1251 feet and due to the alertness of the driller, it is probable that a lot of trouble was averted. He actually cut about six inches of sand before pulling tools from the hole. Noticing the presence of gas, he immediately put out the fire in the forge and dog house and notified the office. Drilling was postponed until daylight and with the drilling of one more foot the gas immediately increased. Since the wind was blowing from the wrong direction, further drilling was postponed. Texas Gas tested the well at this time for 3.6 MMCF.

Even at this point, we were still thinking about oil, not dreaming that we were sitting on top of a commercial gas pool. Because of wind and weather conditions, it was two days before drilling was resumed. It was estimated that an additional three feet of hole were made. By this time, the gas was really roaring and a test by Western Kentucky Gas showed 18 MMCF through eight inch pipe. As we had approximately 400 feet of open hole, the problem now was to kill the well and get casing cemented on top of the sand. The problem didn't seem too great, but what seemed to be a simple operation ended up taking three days and the cementing of three strings of pipe. By this time, the well had been open five days and an estimated 65 MMCF of gas had been lost. After drilling the plug, the well was still testing 13 MMCF with a bottom hole pressure of 529 pounds.

A confirmation well was drilled 1000 feet south of the discovery well in November 1962. This well was drilled with rotary tools and the entire Waltersburg sand section was diamond cored. In this well, we set pipe through the sand and the upper 16 feet were perforated. This well ultimately tested 28 MMCF per day with a bottom hole pressure of 529 pounds. The results of core analysis, drill stem testing, and electric logging show 32 feet of gas sand, 18 feet of gas and water sand, and 18 feet of water sand.

The third well was drilled 1000 feet south of the number two well and since we were fairly certain as to the water table, we only cut 10 feet of sand, stopping 13 feet above water. This well tested 10 MMCF with a shut-in pressure of 517 pounds.

As of the present, there are three gas wells and seven dry holes which fairly well outline the gas area.

TRAP

As shown by the maps and cross section, the type of trap for this pool will have to be classified as stratigraphic. The trap is formed by the grading of the good Waltersburg sand into a shaly dirty sand to the east which is structurally up-dip. Any structure that is present is only reflected on the horizons above the Waltersburg sand and this is due to differential compaction above a thickened sand bar. These ideas are best shown by the structure map on the base of the Lower Menard limestone (fig.1) and the east-west cross section (fig. 3). This cross section covers the interval from the Vienna limestone upward to the base of the Lower Menard from east to west. This thickening reflects the build up of the Waltersburg sand and also coincides with the highest part of the structure on the Lower Menard limestone. From the northeastern well to the southwestern well, the

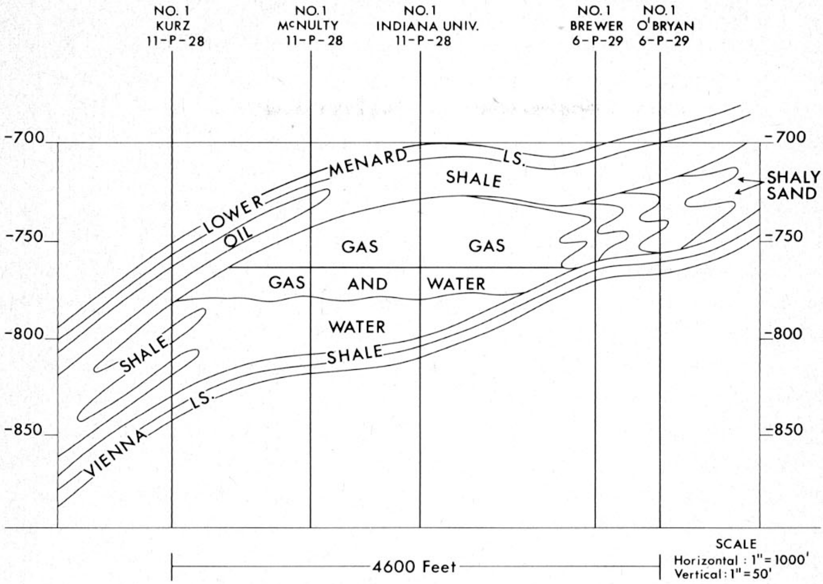

Fig. 3. East-west section across Bon Harbor Gas pool.

interval between the limestones thickens from 61 feet to 74 feet and across the main part of the bar this interval thickens to 93 feet. The Waltersburg sand also thickens from 42 feet on the east to 68 feet in the middle, then thins to 40 feet on the west.

To the east of this area, the attitudes of the Vienna and Lower Menard limestones are very similar, but as you will notice across the gas pool, the dip on the Lower Menard flattens out considerably. The dip of the Vienna limestone does show a slight terracing effect which may account for the deposition of the Waltersburg sand in this area. This slight terracing could have caused a slowing down of currents and wave action with the result that sand was deposited as shown.

The isopach map of the interval between the shallow limestone marker and the base of the Lower Menard limestone shows there is a thinning of approximately 25 feet across the gas area. This thinning can only be attributed to the Waltersburg sand bar.

STRATIGRAPHY AND RESERVOIR CONDITIONS

In the Tri-State area the Waltersburg is primarily a shale section in the Chester Series of the Upper Mississippian. However, in certain areas shale deposition has been interrupted by the deposition of bar-like sandstone bodies. These sand bars were formed along a shoreline environment as the result of wave and current action. The Waltersburg belt of sand deposition is a zone approximately 15 miles wide in a north-south direction and 60 to 75 miles long in an east-west direction. This belt roughly parallels the Ohio River in Indiana and Kentucky and extends into southeastern Illinois.

The Bon Harbor Gas pool is located at the eastern edge of this belt of Waltersburg sand deposition. The Waltersburg sand in this area is definitely a textbook example of an off shore bar. As shown by surrounding wells, the sand dips off sharply to the west or seaward side of the bar and dips gradually to the east or landward side. Also, to the west the sand is fairly clean, but to the east, this sand grades into a silty, dirty sand. The main part of the bar is clean, very fine-grained sand. The shape and sand character of the Waltersburg indicates that it was deposited by waves and currents as a near-shore bar.

As shown by the core analysis, the average porosity of the productive sand is 22%, the average permeability is 175 millidarcys, and the water content is 38%. Also, as shown by core analysis, electric logs, and drill stem tests, the gas in this sand is underlain by salt water. Whether there is an active water drive has not yet been determined.

In the 5 wells that were cored, 2 gas wells and 3 dry holes, another anomaly showed up. In the sand, there were isolated patches and thin laminations of dark material which appeared to be shale. Upon analysis, this material proved to be 75% carbon and under heat the material burned to a red ash residue. The presence of this material also indicates an environment conducive to the formation of off shore sand bars.

GAS ACCUMULATION

As has been noted before, the production of gas from the Waltersburg appears to be unique in this area. A possible explanation for the accumulation in this area is based on the theory that any hydrocarbons are produced as a result of the breaking down of complex organic molecules. This breakdown is accomplished by chemical and physical reactions. Assuming this theory to be true, the formation of gas in this area is primarily the result of the physical reactions which took place. These physical actions were heat and pressure. At the time that heat was helping to convert the organic material surrounding this sand bar into methane gas, differential pressures which resulted from compaction and earth movements were taking place. These pressures added to the heat necessary for conversion of carbonaceous molecules to gas and also caused movement of gas into the reservoir.

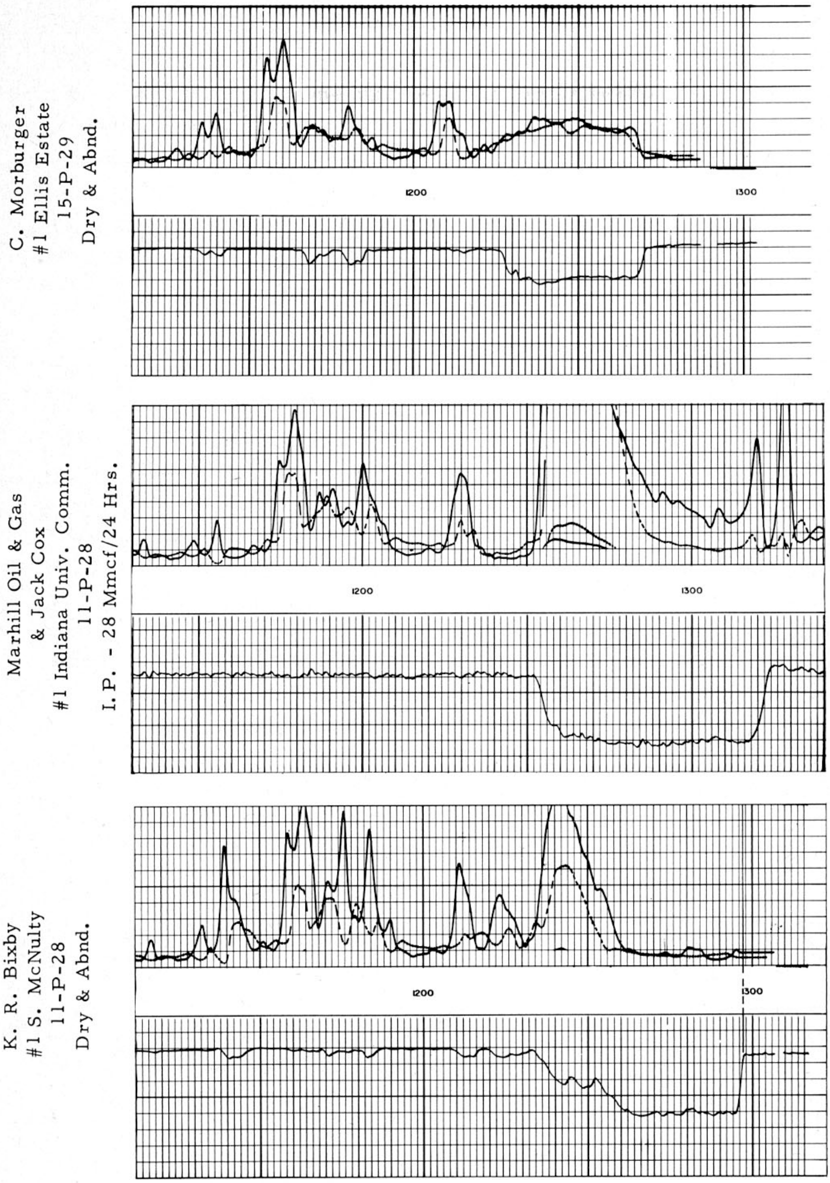

Fig. 4. Electric logs illustrating Waltersburg sand conditions in east-west direction across Bon Harbor Gas pool.

Of the source material, approximately 99% was converted into gas and the remaining 1% was left as the carbonaceous material which is found in this sand.

As to why gas, rather than oil, has filled this reservoir, it can merely be stated that optimum conditions for the formation of gas rather than oil existed. However, I believe this explanation can be carried a little farther. This accumulation is probably a combination of the following factors:

1. Environmental conditions.
2. Type of source material.
3. Complete consumption of source material.

As a result there could never have been a commercial oil pool in this small sand bar.

PRODUCTION AND RESERVES

In December 1962, a four inch line was laid and the first gas was run on January 1, 1963. It was deemed wise to hold production to a maximum of 2 MMCF per day to avoid any possibility of water coning and to maintain equal pressures on the three wells. As of May 15, 1963, pipe line runs have totalled 302 MMCF. This combined with an estimated 65 MMCF that was lost gives a total of 367 MMCF that has been produced from this pool. Current rate of production is approximately 1 MMCF per day. As yet, it is difficult to estimate the resrves for this pool. However, using core analysis and an isopach map of the area, the total reserves as of January 1, 1963, approximated 950 MMCF. This reserve figure is based on 3,000 AC/FT of effective gas sand, and is ultraconservative in that it results from a low estimate of the total effective gas sand. In April, dead weight pressure tests were run and using the pressure volume method of estimating gas reserves, it seems likely that the total reserves as of January 1, 1963 should have been between 1,500 MMCF and 2,000 MMCF.

CONCLUSION

This paper, although dealing primarily with the discovery and conditions of this gas pool, also shows that gas production in Western Kentucky, can be very rewarding. It is now easier to get pipeline connections and this coupled with the increased demand for gas will result in Western Kentucky operators looking for gas as well as oil.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Messrs. Jack Gox, William R. Hildebrand, Larry Marsh, D. C. Benson, and A. C. Boyd for their assistance in preparation of this paper.

OIL EXPLORATION IN HOPKINS COUNTY, KENTUCKY RELATIVE TO THE HANSON OIL POOL

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ABSTRACT

Hopkins County, Kentucky is located in the heart of the West Kentucky Coal Field. Oil was first discovered in Hopkins County in 1924 with the discovery of the Mortons Gap pool. Its next discovery, Bells Ferry, was not until 1951. The Hanson pool discovered in 1962 is the largest pool to date, having produced more than 600,000 barrels of oil to May 1, 1963. Production is from multiple horizons with the Tar Springs Sandstone being the largest of the reservoirs, covering approximately 440 acres. The geology is complicated with much faulting and deformation. Oil traps should be abundant but up until the discovery of Hanson, many structures drilled had poor reservoir rocks. Prospecting is difficult as subsurface information is scarce. Surface geology can be done in many areas. The increased drilling activity should turn up more oil and gas pools.

LOCATION

Hopkins County is located in the heart of the West Kentucky Coal Field. Madisonville, its county seat, is approximately 100 miles north of Nashville, Tennessee and 50 miles south of Evansville, Indiana. Its area covers the Carter Coordinates 21 through 27 from West to East and H through M from South to North.

HISTORY OF HOPKINS COUNTY

Being located in the heart of the West Kentucky Coal Field, coal has naturally been the county's principal mineral product. Until 1962, oil production has played a small role in the economy of the county. The discovery of Hanson was like waking a sleeping dog as Hopkins County is one of the oldest producing counties in the West Kentucky Coal Basin, with oil first being discovered in 1924. The Mortons Gap pool was discovered by Copper Flash Oil Company with the primary pay horizon being in a Pennsylvanian sand. This pool produced approximately 100,000 barrels of oil. From this discovery there was an elapsed time of almost 30 years until the discovery of Bells Ferry pool in 1951, with the majority of this pool lying in McLean County. The Pond River pool was discovered about the same time, but except for a couple of wells, its commercial value is questionable. The Oak Hill West pool was discovered in 1957 and has produced more than 300,000 barrels of oil. The Hanson discovery is by far the best discovery in Hopkins County to date.

Fig. 1. Index map showing location of Hanson pool, Hopkins County, Kentucky.

Although production dates back to 1924, the accumulative production up to the end of 1962 was approximately 880,000 barrels of oil, excluding the Hanson pool. The Hanson pool was responsible for a considerable increase in oil production for Hopkins County with over 220,000 barrels being produced in 1962, roughly 25% of the total past production. The Hanson pool having leveled off at approximately 3,000 barrels daily production, the 1963 production should be over 1,000,000 barrels. It is hoped this increased wealth from oil will continue to grow with the discovery of more large fields, and from the increase in wildcat activity in Hopkins County, this could very well be.

In my discussions with geologists and other oil company personnel including production men and drilling contractors, Hopkins County has been classified a faulted area where exploration is difficult, drilling the hardest in Western Kentucky, and production in many cases creating problems. Let's look into it and see if it is as bad as some of us have been led to believe.

REGIONAL STRUCTURE

The dominant regional structural feature of Western Kentucky is the coal basin in which Hopkins County is located. The differential settling which formed the basin was going on during Devonian, Mississippian and Pennsylvanian time, for some time after the desposition of the Pennsylvanian coal measures, and during the time interval represented by the major unconformities at the base of the New Albany Shale and at the base of the Pennsylvanian. The Mississippian and Pennsylvanian strata are in general thicker in Hopkins County than on the flanks of the basin. Some of the deepest and thickest sediments of the coal basin lie in this area.

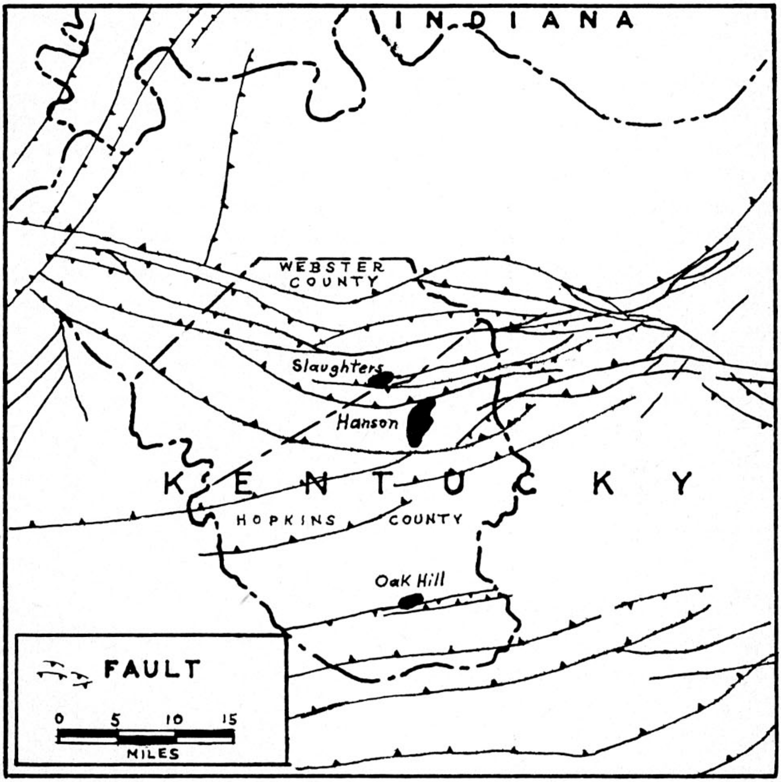

Fig. 2. Location of Rough Creek fault zone and associated faulting in western Kentucky.

Another regional structural feature of Western Kentucky is the Rough Creek fault. It is located north of Hopkins County but faulting associated with this deformation is located throughout Hopkins County and is considered to have occurred in post-Pennsylvanian times. William L. Russell suggests the Rough Creek fault system is an extension of the Ouachita deformation from the Mississippian embayment and even suggests this structural feature began to develop in Mississippian time. He suggests evidence of this was obtained from the thin Mississippian sections logged on wells drilled on the Rough Creek uplift. Associated with this major faulting are undoubtedly many anticlinal folds, on one of which we have located the Hanson Oil pool.

Another structural feature I'd like to touch on is the "Moorman Syncline." The Moorman syncline is a name many of us have heard mentioned and have made it synonymous with a contagious disease, something you want to stay away from. It extends from Union County on the west, through Webster, Hopkins, McLean, Muhlenberg, Ohio, Butler, Grayson and Edmonson counties to the east. It makes one think of some of the old geologists who wouldn't dare drill in the deeper parts of the sedimentary basins. They concentrated on the rim areas of the basins as supposedly there couldn't be anything but salt water in those deep lows. It is time to change our thinking on the Moorman syncline and possibly rename it, as this dominant structural feature lies over too extensive an area to carry an insignificant local name. Regardless of what we call it, it should not be a barrier to exploration. Two large discoveries have been along the flank of this feature in the past year. The Hanson pool, of course, and the Noffsinger School or Midland Benoist Gas discovery in J-28, Muhlenberg County, Kentucky. If there are any more traps in close proximity to this feature, and there should be, the pools could very well be as good as Hanson as the hydrocarbons migrating from their source beds such as the richly bituminous New Albany Shale or the bituminous shales of the Chester Series would be trapped updip from the trough in the folds and wrinkles associated with it.

HANSON POOL

The Hanson pool warrants a few more details. I have referred to it previously and, of course, you have all heard of it. The discovery well of the Hanson pool was the #1 S. W. Brown, the operator being Shulman Bros. and Pure Oil Company. It is located by Carter Coordinates in section 16-L-25 and was spudded on May 22, 1962. Brandon Nuttall, petroleum geologist, is credited with this discovery.

Since the discovery well up to May 1, 1963, approximately 65 producers have been completed. Multiple pays have proved commercial; namely, the Tar Springs Sandstone, Hardinsburg Sandstone, Cypress Sandstone, Benoist Sandstone, and Aux Vases Limestone of the Chester Series and the O'Hara Limestone of the St. Genevieve Series, all of Mississippian age. The Hanson pool is an asymmetrical fold with 20 to 30 feet of structural closure. The field is immediately truncated to the north by an almost east-west high-angle normal fault. The hade of the fault is around 65-70 degrees and displacement varies from 450 feet to the east and 100-150 feet to the west. A small near vertical

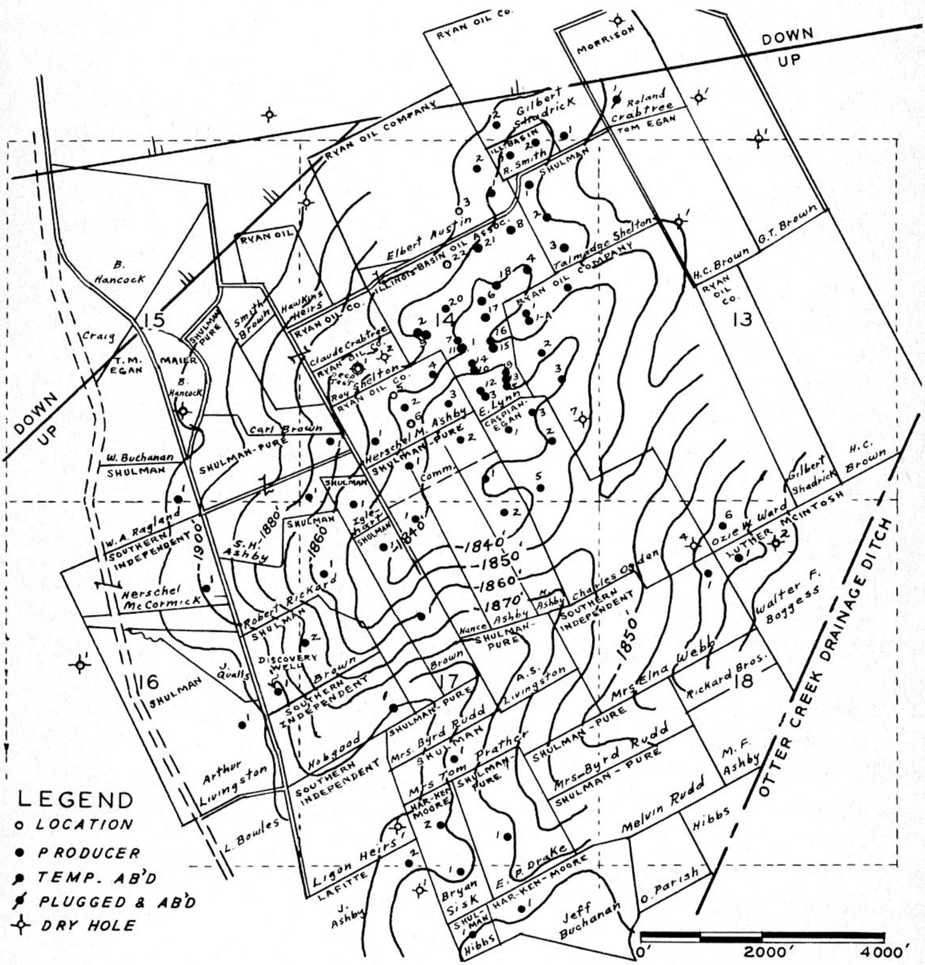

Fig. 3. Structure map of Hanson pool area, L-25, Hopkins County, Kentucky. Structure contours drawn on base of Vienna Limestone; contour interval is 10 feet.

normal fault occurs on the northwest side of the structure, the displacement diminishing to the southwest.

The structure map is on the base of the Vienna Limestone as the Tar Springs sand is the largest of the reservoirs, covering approximately 440 acres with an average thickness of 15 feet. Accumulative production of the Hanson pool from all zones through May 1st was approximately 620,000 barrels. The current price being paid for oil produced from the Hanson pool is $2.85 per barrel; hence the value of oil produced to date is more than $1,770,000.00 with over $1,500,000.00 of this total credited to the working interest. Some of the initial wells drilled in the pool paid out in a matter of days due to the large flows from the O'Hara Limestone. However, it is felt the entire field development is not paid out but at the present production rates, it should be very shortly. From the production statistics, this rates as an extremely good oil pool. Initial potentials were as high as 2,000 barrels daily from the O'Hara oolitic porosity, but even with the large flows from the O'Hara the pool did not reach its peak production until April of 1963. This was after the lime had declined rapidly from loss of pressure due to the large amounts of gas flared and the completion of sand wells commenced. The rapid production increase caused by the completion of sand wells is expected to have a more gradual decline.

FAULTING, STRUCTURES, AND RESERVOIR CONDITIONS

Faults are prevalent throughout Hopkins County. Most of them, especially those with larger displacements, we already know about from surface and subsurface studies. Undoubtedly there are minor sliver faults associated with the major faulting with 10 to 50 feet displacement. These will be found with more concentrated drilling or more detailed surface work. The locations of these faults are very important to us in prospecting for oil and gas. In addition to the faults formed during periods of deformation, many anticlinal folds and noses were also formed creating traps for the accumulation of oil and gas. The faults themselves in many cases form a barrier preventing escape of hydrocarbons by the impervious conditions created along the fault zone. But all is not good because not only have these faults created many possible reservoir traps, but due to the number of them and sometimes their close proximity to each other, they have played havoc with our porosity and permeability conditions. In these belts of steep folding and pronounced faulting the sandstones are in many places too hard and tight for production of appreciable quantities of oil, gas, or water. The highly tilted sandstones near the faults are hard and tight because of the deposition of siliceous cement between the grains. Some of the sandstones in the area of maximum disturbance are almost quartzites. The reservoir rocks in the Chester Series of sediments in Hopkins County up to the development of the Hanson pool were the problem rather than structure. Structures drilled had poor reservoir rocks; they were markedly patchy or sandstones were distributed in small lenses, good examples being Bells Ferry pool and the Pond River pool. The reservoir sandstones may be absent entirely, being replaced by shale or limestone or they may be present but too shaly, too limy, or too tightly cemented. It is a common occurrence to find the sandstones containing oil but too impervious for production. Even though these conditions exist and will repeat themselves time and again, the exploration geologist must work harder than ever as the Hanson pool reservoir conditions indicate sand lenses of good quality covering extensive areas are present in Hopkins County. Our search will be concentrated on finding more of these commercial reservoirs with good sand conditions.

PROSPECTING

Prospecting has always been difficult for the oil hunter although there are a few who seem to drill just about anywhere and strike it. Since most of us are not in this category, we have to use every means at our disposal to come up with decent prospects. The more expensive methods of finding prospects such as seismic, gravity, core drilling, etc., are not tools easily afforded by the independent operator and their merit for this particular area is somewhat questionable. The best tools we have at our disposal are the petroleum geologist and the drilling rig. The geologist can use whatever subsurface data is available which in many cases is scarce. Much surface information is available to the geologist who wants to trample the hills and dales of Hopkins County. There are certain Pennsylvanian formation, particularly the coals, which are correlative over widespread areas and important structural data can be obtained from these surface outcrops. Faults can be located by formation changes or even changes in soil composition. It has been said the coal highs do not always carry through to our prospective producing formations in the Chester and Ste. Genevieve series of sediments Undoubtedly this can be shown in a few cases but more times than not these structures will drill out with possibly slight shifts with depth.

We must consider possible reservoir conditions where our subsurface data is limited. We will possibly encounter reservoir conditions mentioned earlier in the paper. This is part of the gamble and it wasn't until four holes were drilled in the Hanson pool that reservoir conditions were found that could be called favorable for commercial production. Most of us cannot afford that on a single prospect but sometimes it takes that financial perseverance to reap the benefits.

Another problem we encounter in prospecting and ever in field development is the parallelism of the Chester sediments. Due to the lenticularity of the sandstones we get rapid thinning of intervals due to compactions of the shales and thickening of interval due to a buildup of sand deposits.

With this in mind, it becomes important to use a marker bed for mapping structure as close in depth as possible to the particular horizon or horizons we hope to find oil or gas bearing.

In summarizing prospecting in Hopkins County, exploration has not been made less difficult, and drilling techniques have improved to the point where contractors do not hesitate to bid on prospective holes to be drilled. Penetration rates have improved tremendously. Production techniques have also improved to the point where heretofore low permeable sands were bypassed, they can now be fractured and brought in as commercial wells.

Not to be neglected in our prospecting is possible gas production. The number of gas wells put on production the last few years has increased substantially. Commercial gas was first discovered in Hopkins County around 1930 but due to the lack of market and expensive transportation cost it was not searched for, and, if found, was plugged and abandoned and not utilized. The pipeline routes of the large transmission companies were across Western Kentucky and particularly Hopkins County. With this development, known gas fields and gas discoveries of recent years came within reach of markets. It took only the construction of trunk lines of small diameter pipe to the existing transmission lines and the operators were in business. In some cases more profits can be made from gas production than oil.

CONCLUSION

Since it took almost 40 years of rather sporadic exploration to come up with a major oil pool in Hopkins county, it is not inconceivable with a diligent and concentrated search there are more Hansons waiting to be tapped. Most investors in the oil business want to be in on the large pools. Since the Hanson discovery, the potential of Hopkins County is there and everyone wants to be in on the next one. To be facetious, I've heard 125% of the total acreage in Hopkins County is leased, but even if it were, there are still deals to be made, farmouts and joint ventures, so everybody get on the bandwagon and let's discover many more Hansons.

THERMAL RECOVERY BY IN SITU COMBUSTION

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ABSTRACT

In situ combustion is a thermal method of oil recovery, where necessary energy is furnished by injecting air into the reservoir and burning part of the crude oil as fuel. It has had its most effective application in the production of low-gravity viscous petroleum. This talk together with an 18-minute color movie presents part of one company's laboratory and field activities in this area.

It is estimated that the crude oil discoveries to January 1, 1962, in the United States exceeded 346 billion barrels. Only about one-third of this 346 billion barrels has or will be produced by primary or conventional means. It is the staggering figure of 231 billion barrels of discovered but so-called unrecoverable crude oil that is causing industry to spend tremendous sums of money for research and development on new processes, such as fire flooding. These new processes, sometimes known as exotic processes, are becoming more inviting economically because the costs of proving new deposits of petroleum are rapidly increasing.

The use of heat to stimulate oil production has received considerable attention in recent years. Several thermal recovery methods are in various stages of development and application; and they may be of more potential benefit than water flooding or gas injection because recoveries above 50 percent can be expected.

Thermal methods as known today seem to have their most effective application in recovery of low-gravity viscous crude oils, but are certainly not limited to the production of these heavy crudes. To date, the application of thermal recovery to produce high-gravity oils has not been extensively developed because other processes, such as water flooding or gas injection, are being used effectively to produce these oils. One exception to this would be the use of heat in combating paraffin deposits. The oldest known application of heat to an oil reservoir is its use in a production well to improve recovery rate and ultimate recovery. Another way to use heat is by the direct injection of hot fluids, hot gasses, water, or steam to reduce oil viscosity.

The subject to be discussed on this program is that of underground combustion or fire flooding, also known as in situ combustion.

This is a thermal oil recovery method where the necessary energy is furnished by injecting air into the reservoir and burning part of the crude oil as fuel. The forward or conventional in situ combustion process consists basically of first, injecting air into a reservoir to establish a flow path for movement of combustion gasses; second, igniting the crude oil at the injection well; and finally, propagating the combustion front by continued air injection. The burning zone advances, more or less radially from the injection well, moving oil to the surrounding production wells. As indicated above, the fuel for the process is supplied from the crude oil and consists mainly of a heavy material of a coke-like nature that has been deposited on the sand during the distillation and cracking of the crude oil ahead of the combustion front.

Recovery of crude oil by underground combustion is an old idea. The process was patented in about 1914 in the United States. Numerous other patents have issued since. Since about 1952, a number of oil companies have conducted laboratory and field tests investigating in situ combustion as a thermal recovery method.

Continental Oil Company has prepared a movie, "Trial by Fire," which shows some of their research and field activities in the field of in situ combustion. Laboratory equipment and demonstrations are shown. Animation is used to describe application of fire flooding to the North Tisdale area. Actual field scenes are also presented showing equipment and the ignition of an injection well.

The North Tisdale field was discovered in 1953. Twenty-five wells were drilled on ten-acre spacing. These wells were drilled to the 900 ft. Curtis sand where an average of about 50 feet of oil sand is present. The initial oil in place was calculated to be 1200 barrels per acre-foot. The decline curves indicated that less than 10 percent of the original oil in place would be recovered by primary means, which was a limited water drive. This is because the Curtis crude has a viscosity of 300 cp at reservoir temperature and is a dead oil.

Since combustion has been initiated at North Tisdale, the field production has climbed from 4500 barrels per month to more than 10,000 barrels per month. During this time the production well nearest the injection well increased from 120 barrels per month to 1800 barrels per month. As a result of this increase in production, a pipeline has been run into North Tisdale so that the crude would not have to be hauled by truck to Casper, Wyoming, a distance of 70 miles. Since the fire flood began, approximately 430,000 barrels of oil have been recovered; 240,000 barrels of this are credited to the fire flood. Ultimate recovery is estimated at about 50 percent of the original oil in place with another 10 or 15 percent of the oil saturation being burned as fuel for the combustion front. Presently, operations are being expanded at North Tisdale and additional wells have been ignited.

THE APPLICATION OF FRACTURING IN THE OIL SPRINGS POOL

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ABSTRACT

First flood work with the Weir sand in the Oil Springs pool used shot completions in a five-spot pattern development of 2.50-4.00 acres per pattern. By 1959, flood development was moving into areas of tight sand and, with the movement into these areas, the injectivity of shot completions was falling to levels that would not permit continued flood development. The operators in the pool then turned to fracture completions to increase flood pattern conductivities. Fracture completions increased flood pattern conductivities to a level which, in conjunction with wider spacing of development wells, restored profitability to the flooding of the Weir sand in this pool. This paper covers briefly the economics, techniques, and results of fracture flood development in this pool.

HISTORY

The Oil Springs pool of Magoffin County, Kentucky, was discovered in June 1919 with the completion of the Bedrock Oil Company's No. 1 Milt Wheeler as an oil well in the Weir sand. The pool was developed for primary production in the early 1920's and primary development was essentially completed by 1930. The pool had a peak production of about 3,500 BOPD in 1923. Even though several air and gas repressuring projects were started in the 1930's, production from the pool continued to decline. The success of the Cumberland Petroleum Company's pilot waterflood project on the L. C. Bailey lease, initiated in the fall of 1948, resulted in extensive flood development of the Weir sand in the 1950's. This flood development was on a five-spot pattern, using shot completions, with pattern areas ranging form 2.50-4.00 acres. This phase of flood development of the Oil Springs pool has been well covered by two papers presented at the Kentucky Oil and Gas Association annual meetings. The first paper was presented at the 1956 meeting by Mr. Arthur C. Simmons, a prominent geologist and petroleum engineer, from Bradford, Pennsylvania. The second paper was presented at the 1960 meeting by Mr. W. H. Litton, superintendent and engineer of the Bedrock Petroleum Company.

THE PROBLEM

The Oil Springs pool is located along the crest and the west flank of the Paint Creek anticline south of the regional Irvine-Furnace-

Paint Creek fault. The Weir sand is best developed, i.e., more porous and permeable, in the east and south. As one moves north and west, the sand becomes less porous and permeable. Naturally, the first flood development in the pool was in the prolific areas of the better sand development. By 1959, flood development was moving into the areas of tighter sand development. Due to the decreasing injectivity of the shot completions, it was apparent to most operators that continued flood development would not be feasible with the then current completion methods. The following table gives a typical example of the flood economics at that point:

TABLE 1

TYPICAL FLOOD ECONOMICS BY SHOT COMPLETIONS IN 1959

	Basis		
	Pattern	Acre	W.I. Barrel
Pattern Area, Acres	3.67	....	....
Ultimate Flood Recovery, Barrels	18,350	5,000	....
Flood Life, Years	14	....	....
W.I. Flood Recovery, Bbl. @ 0.875 of Gross	16,056	4,375	....
W.I. Revenue @ $2.87 Per Barrel	$46,081	$12,556	$2.87
Direct Operating Expense			
Operating Expense @ $30 per well-month	$10,080	$ 2,747	0.63
Taxes—State and Local @ $0.08 Per Barrel	1,284	350	0.08
Total Direct Operating Expense	$11,364	$ 3,097	0.71
Direct Operating Profit	$34,717	$ 9,459	$2.16
Development Expense			
Producing Well	$10,000	$ 2,725	$0.62
Injection Well	8,000	2,180	0.50
Other	500	136	0.03
Total	$18,500	$ 5,041	$1.15
Net Profit Before Taxes	$16,217	$ 4,418	$1.01
Net Profit—Investment Ratio	0.88	0.88	0.88

The above table does not include district, administrative, or overhead expenses, nor have any deductions been made for income taxes, as these expenses, nor have and deductions been made for income taxes, as these expenses vary widely from company to company. Furthermore, the net profit has not been discounted. Even without the inclusion of these expenses, the net profit—investment ratio of one, after inclusions of these expenses, before they undertake new development. Consequently, it is readily apparent that the economics of continued flood development with shot completions was unfavorable.

If flood development in this pool was to be continued, the operators had to either increase recovery efficiency to recover more oil with the same investment for a lower per barrel investment, or they had to increase well conductivity and well spacing to lower total and per barrel investment for the same recovery. As the secondary recovery methods with a greater recovery efficiency than waterflooding were still in their infancies, unproven and expensive, the operators felt that one of the newer stimulation methods would probably offer the best chance of increasing the capacity of the flood wells to a level that would permit continued flood development. As hydraulic fracturing, or *fracing*, had been used successfully to increase the capacity of flood wells in other areas, it was given first consideration by the operators. In 1959, two operators began experimental trials of frac completions in flood development. This was done rather reluctantly because of the ever inherent danger of "channelling" water with frac completions, but the flood economics of shot completions made some new apporach mandatory. This paper will cover fracing techniques, results, and flood economics of frac completions.

FRACING TECHNIQUES

Fraced wells are drilled in the same manner as shot wells. The only difference between the wells is in their completion methods. On a fraced completion, after total depth has been reached, 4½" OD, 9.50#, J-55 seamless casing is run and cemented. The casing is then perforated and the well fraced.

Ideally, in fracing a well in a flood, the optimum treatment would obtain a separate short-radius fracture through every perforation. Such a treatment would minimize the reduction in the areal sweep efficiency, would eliminate "channelling" of water between inputs and producers through interconnection of fractures, and would assure complete vertical coverage of the formation. In laboratory work with models, Dyes, Kemp, and Caudle (1958) have shown that producing and injection wells can both be fraced without a substantial reduction in areal sweep efficiency, so long as the fracture length does not exceed one third of the distance between the input and the producer. The frac treatments were designed to obtain this optimum condition.

First frac treatments used ball sealers to obtain multiple-fractures. The casing was perforated with two shots per foot and the well fraced with from three to six stages under pressures from 1000-2500 psig for rates from 18-10 BPM. The treatment was staged by the running of ball sealers. The theory was that each set of ball sealers would close off the performations than taking fluid and a new set of performations would be opened for initiation of a new fracture. The problem in this type of treatment is the uncertainty as to whether the ball sealers shut off the perforations taking fluid in all cases. On some treatments, treating pressures and rates indicated almost "text book" treatments, as a sharp pressure increase and an accompanying rate reduction were obtained with every set of balls. On such treatments, a separate fracture is undoubtedly obtained with each stage. However, on other treatments, the treating pressure would continue to fall throughout the treatment without any sharp increase to indicate closure of any perforations by the ball sealers. On such treatments, the number of fractures obtained is a moot question.

Although satisfactory results were obtained on most wells with the foregoing type of treatment, there were a few breakthroughs between inputs and producers. The first approach toward improvement of the frac-treatment technique was a reduction in perforation density. Experimental work by the laboratories of the major oil companies and the various service companies showed that the capacity of perforation density of two shots per foot was much greater than needed for the fracing rates being used, so perforation density could be reduced without any adverse effects. Consequently, one operator reduced perforation density to one shot per foot and continued the same treatment technique otherwise. This technique presented no new problems. Theoretically, the reduction in perforation density would enhance the chances of obtaining a separate fracture with each stage, as the increased distance between perforations would lessen the chances of communication between perforations through the cement sheath behind the pipe and would also lessen the chances of the fractures connecting within the formation. This treatment technique, though, still had the same major fault of the first technique, i.e., the uncertainty as to whether closure of the perforations taking fluid was obtained with the ball sealers in all instances.

Laboratory work by the major oil and service companies indicated that any perforation has a critical capacity above which any increase in rate can only be obtained by an excessive increase in pressure. This critical capacity was thought to be on the order of 1.50-2.00 BPM for a 3/8" jet perforation. This work provided the basis for the next improvement in fracing technique. It was theorized that every perforation could be opened by increasing the treating rate above combined critical capacity of the perforations. Then, a separate fracture could be obtained through each perforation. One operator tested this theory. Perforations were limited to one shot every two feet for a total of nine to thirteen shots per well and treatment rates were raised to 20-30 BPM. The wells were treated with 3,000-6,000 gallons of fluid in one stage. Radioactive sand was run at the close of treatment on the first wells and a tracer survey was then run. Based on information gained from these surveys, the operator estimated that at least eighty percent of the perforations had taken sand on every treatment. In view of these results, the operator continued use of this frac technique. A total of fifteen producing wells have been so treated by the operator. There has not been a breakthrough from an input into any of these producers. However, based on the information obtained during these treatments, the critical capacity for a perforation appears to be on the order of about 2.50 BPM instead of the 1.50-2.00 BPM reported by the literature.

As previously mentioned, there have been some problems with fracture breakthroughs between inputs and producers and the consequent "channelling" of water between the wells. This, though, has been a minor problem since it has occurred on less than ten percent of the wells. It is not believed that such breakthroughs will have any serious adverse effect on the economics of frac flood development. One observation of interest on these breakthroughs is the apparent orientation of the interconnecting fractures. To date, the line of breakthroughs has always been in a northeast-southwest direction.

RESULTS

The operators in the pool have been well satisfied with the results obtained so far in their programs on frac flood development. It is estimated that flood pattern conductivities have been increased about five-fold. In other words, a well completed by fracing will have an injectivity five times as great as its injectivity would have been as a shot completion. Hence, the level of injectivity has been raised from about 10 BWPD level of the shot wells to about 50 BWPD. The increase in productivity for fraced producers has been on the same order. This five fold increase is probably a minimum increase as, generally speaking, fraced flood development has been in much less permeable areas than adjacent shot completion flood development. This increase in flood pattern conductivity has permitted an increase in the size of flood patterns. Most operators are now shooting for about a ten-acre flood pattern for fraced development instead of the pattern area of about four acres used with shot completions.

The success of fraced completions can best be illustrated by the number of wells so completed. In the last four years, 126 injection wells and 124 producing wells have been completed by fracing. This fraced flood development covers an area of about 1,200 acres. Fraced completions now produce about 1,460 BOPD for an average of about 12 BOPD per producer. Fraced producers account for sixty percent of the production of the operators using this method of completion and about fifty percent of the total production from the Oil Springs pool.

Enough history is not available on the frac flood development for an accurate estimation of the ultimate flood receovery. However, present indications are that the recovery from the fraced areas will be comparable to that of the adjacent shot areas. Furthermore, this oil will be recovered over a shorter flood life with reduced development and operating expenses. The reduction in development and operating expenses has substantially improved the economics of flooding. There is a chance that flood recovery with fraced completions will be above that with shot completions. This could be brought about by a higher economic water cut and a better vertical coverage of the sand.

The use of fraced completions has drastically changed the economics of flooding the Weir sand in the Oil Springs pool. This is well shown by the following table which gives the economics for a typical frac flood:

TABLE 2
TYPICAL FLOOD ECONOMICS BY FRAC COMPLETIONS IN 1963

	Basis		
	Pattern	Acre	W.I. Barrel
Pattern Area, Acres	10.00	....	....
Ultimate Flood Recovery, Barrels	50,000	5,000	....
Flood Life, Years	10	....	....
W.I. Flood Recovery, Bbl. @ 0.875 of Gross	43,750	4,375	....
W.I. Revenue @ $2.87 Per Barrel	$125,562	$12,556	$2.87
Direct Operating Expense			
Operating Expense @ $40 per well-month	$ 9,600	$ 960	$0.22
Taxes—State and Local @ $0.08 per Barrel	3,500	350	0.08
Total Direct Operating Expense	$ 12,100	$ 1,310	$0.30
Direct Operating Profit	$112,462	$11,246	$2.57
Development Expense			
Producing Well	$ 13,000	$ 1,300	$0.30
Injection Well	10,000	1,000	0.23
Other	1,000	100	0.02
Total	$ 24,000	$ 2,400	$0.55
Net Profit Before Taxes	$ 88,462	$ 8,846	$2.02
Net Profit—Investment Ratio	3.60	3.69	3.69

As shown by the above table, the net profit-investment ratio for fraced flood development is about 3.69. Though this table does not include district, administrative, or overhead expenses, or make any allowance for income taxes, since these expenses vary widely from company to company; the net profit–investment ratio will still remain favorable enough, even after the inclusion of these expenses, to insure continued flood development in the Oil Springs pool. In this pool, the economics of frac-flood development compared to shot-flood development can be summed up as follows: frac-flood development will double the net profit per barrel on a per barrel investment of less than half.

CONCLUSIONS

In the writer's opinion, the following conclusions can be drawn on fraced flood development in the Oil Springs pool:

1. Fraced completions can be safely used in the flood development of the Weir sand in this pool.
2. Fraced flood development has substantially improved the economics of flooding the Weir sand in this pool.
3. Fracing has made possible the flood development of areas of tight sand development that could not have been otherwise flooded due to uneconomical levels of input.
4. Fraced completions have substantially multiplied flood pattern conductivity over that of shot completions.
5. The "channelling" of water between inputs and producers through interconnected fractures is a minor problem in this pool and will not sugstantially affect the economics of fraced flood development.
6. In flood work, frac treatments should be designed to obtain a maximum number of short-radius fractures.
7. High-rate, single-stage frac treatments through a minimum of perforations appear to be the optimum method of obtaining a maximum number of short-radius fractures. Perfection of this technique requires additional work, both in the field and in the laboratories.
8. There is evidence that fractures of the Weir sand in the Oil Springs pool are oriented in a northeast-southwest direction. Additional research is needed on this phenomenon.
9. Additional research is needed on the entire field of fracing for a fuller understanding of the fracing mechanism. Such an understanding would permit an operator to tailor a frac treatment to his requirements.

As most sands in the Appalachian area are similar in their characteristics, the writer feels that the successful application of fracing to flood work on the Weir sand on the Oil Springs pool warrants trials of this stimulation technique in flood work with other formations in this area.

ACKNOWLEDGEMENTS

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GEOLOGY OF THE ST. PETER SANDSTONE IN CLARK AND ESTILL COUNTIES, KENTUCKY

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ABSTRACT

The St. Peter sandstone was derived from erosion of the sandy Knox dolomite, and deposition was controlled by the structural and topographic configuration of the post-Knox unconformity.

The accumulation of gas in the St. Peter sand is in combination structural-stratigraphic traps. It can be shown that the occurrence of thick, well-developed St. Peter sand is related to local thickening of the Chazy-Black River section. Type logs and production history from two producing areas show the reservoir characteristics of the sand.

INTRODUCTION

Three wells in the Trapp area of southeastern Clark County, Kentucky, indicate the existence of a commercial gas field awaiting development in the St. Peter sand of Middle Ordovician age. The three wells have developed a potential open flow of approximately 8 million cubic feet per day of 950 B. T. U. gas, with a shut-in pressure of 600 psig. at an average depth of 1700 feet. One step-out well 1 ½ miles south of the productive area found the sand tight, but recorded shows of oil and gas in the St. Peter. A step-out well approximately one mile east of the area is presently drilling.

During 1948-1949 St. Peter gas production was developed in the Furnace area of Estill and Powell Counties, Kentucky. Twenty St. Peter wells were drilled, of which 16 were productive. These 16 wells developed a total open flow of approximately 100 million cubic feet of 600 B. T. U. gas per day with a 750 psig. shut-in pressure at an average depth of 2950 feet. The high CO_2 content (40% ± by volume) and the low B. T. U. resulted in the gas being used for repressuring the Lockport reservoir in the Big Sinking field. Approximately 205 million cubic feet of the gas was sold commercially for use as fuel in a brick plant at Stanton, Kentucky.

Other wells in the area shown in Plate 1 (Top Knox Structure, in envelope) have had interesting oil and gas shows in the St. Peter, and large-volume water fill-ups from the St. Peter indicate porosity and permeability, and favorable reservoir characteristics in areas where the sand is well-developed.

REGIONAL GEOLOGY

The report area is located high on the east flank of the present Cincinnati arch. Complex normal faulting, and at least four major unconformities, attest to the varied structural history of the area.

Paleozoic rocks ranging in age from Pennsylvanian down to Middle or Lower Cambrian form the known sedimentary sequence for this area. Surface exposures range from Middle Ordovician to Pennsylvanian in age. The South Central Petroleum No. 1 James Hall in western Powell County midway between the Trapp and Furnace areas penetrated 6088 feet of sediments and bottomed in the Rome without reaching crystalline basement.

PRE-ST. PETER

From early Cambrian to Pre-Chazy the dominant positive area in eastern and central Kentucky was located to the northeast in the Lewis-Carter-Elliott County area (Waverly arch of H. P. Woodward), as shown on the "Top of Knox to Rose Run" isopach,(Fig. 1).* The "Tyrone to Knox" isopach (Fig. 2) shows the shift of the positive trend to the present axis of the Cincinnati arch, with subsidence in the Waverly arch area, creating a broad shallow shelf area in northwestern Kentucky.

During Rome time a depositional trough developed in an arcuate pattern around the northeastern positive area as shown in Figure 3, (gravimetric map), resulting in a maximum known pre-Knox thickness of over 600 feet in Martin County, 4000 feet in Breathitt County, and at least 2000 feet in Powell County, as compared with 400 to 500 feet in Elliott, Carter, and Lewis Counties. It is probable that subsidence and faulting of the basement complex controlled the development of the trough. The position of the trough is suggested on regional gravity data, and confirmed by recent deep drilling.

Throughout Knox time the Waverly arch was the dominant positive feature in eastern Kentucky with the highest portion of the arch lying in Lewis County. From a thickness of approximately 1000 feet in the Lewis County area the Knox thickens approximately 1500 feet to the south in Bell County, and approximately 2000 feet to the southwest in Lincoln County. This thinning is due to post-Knox erosion and truncation of the Beekmantown, as well as to depositional thinning within the Knox.

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* The authors wish to acknowledge the use of maps prepared by Edmund Nosow and Wm H. McGuire for their paper presented at the Technical Session of the Kentucky Oil and Gas Association, Lexington, Kentucky, June 8, 1962 in preparing their Figures 1, 2, and 3.

The Rome trough is probably bounded on the north by a system of faults, many of which were recurrent throughout the Paleozoic, and some of which were active as late as Tertiary. Portions of the Irvine-Paint Creek fault system are believed to have had their inception during early Cambrian, and the present lineation coincides with

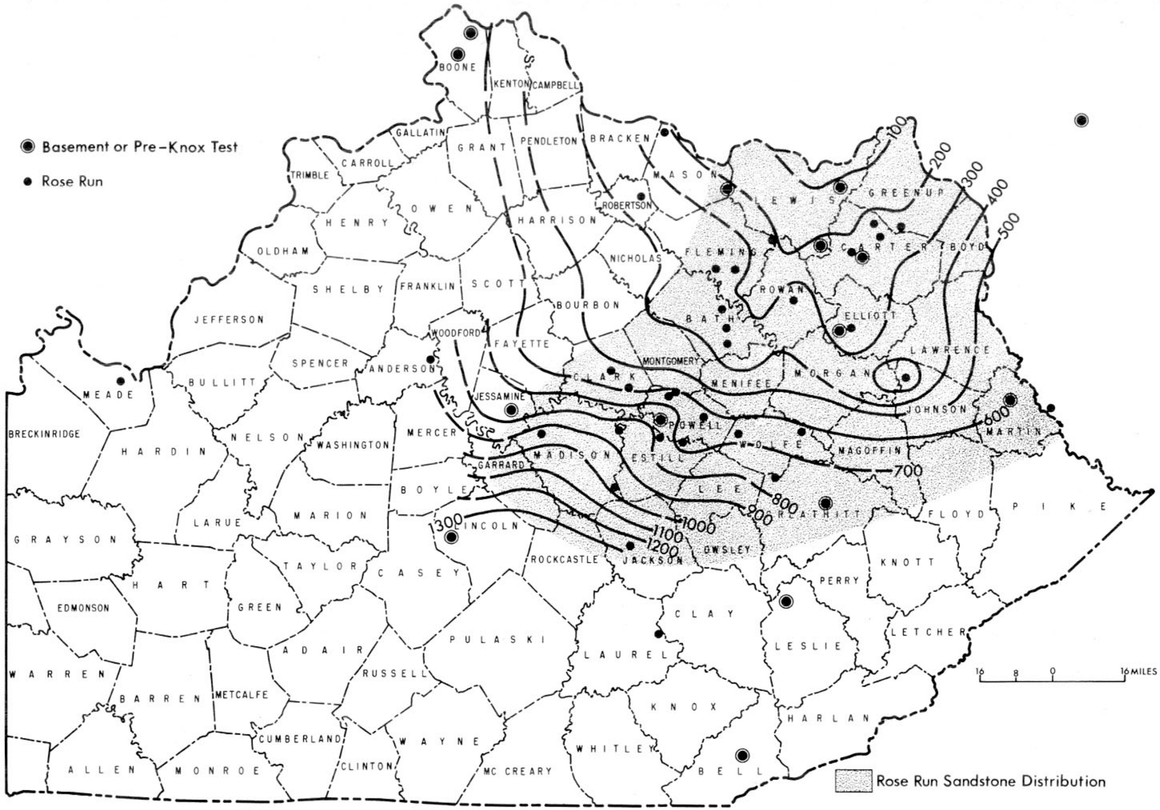


Fig. 1. Isopach map, top of Knox Dolomite to top of Rose Run Sandstone, showing thinning over positive area in northeastern Kentucky (Waverly arch).

the early Cambrian east-west hinge line. Additional faulting is believed to have been initiated as a result of the shift of positive areas from the Waverly arch to the present Cincinnati arch during early Middle Ordovician.

During the period of post-Knox erosion of the Waverly arch sands

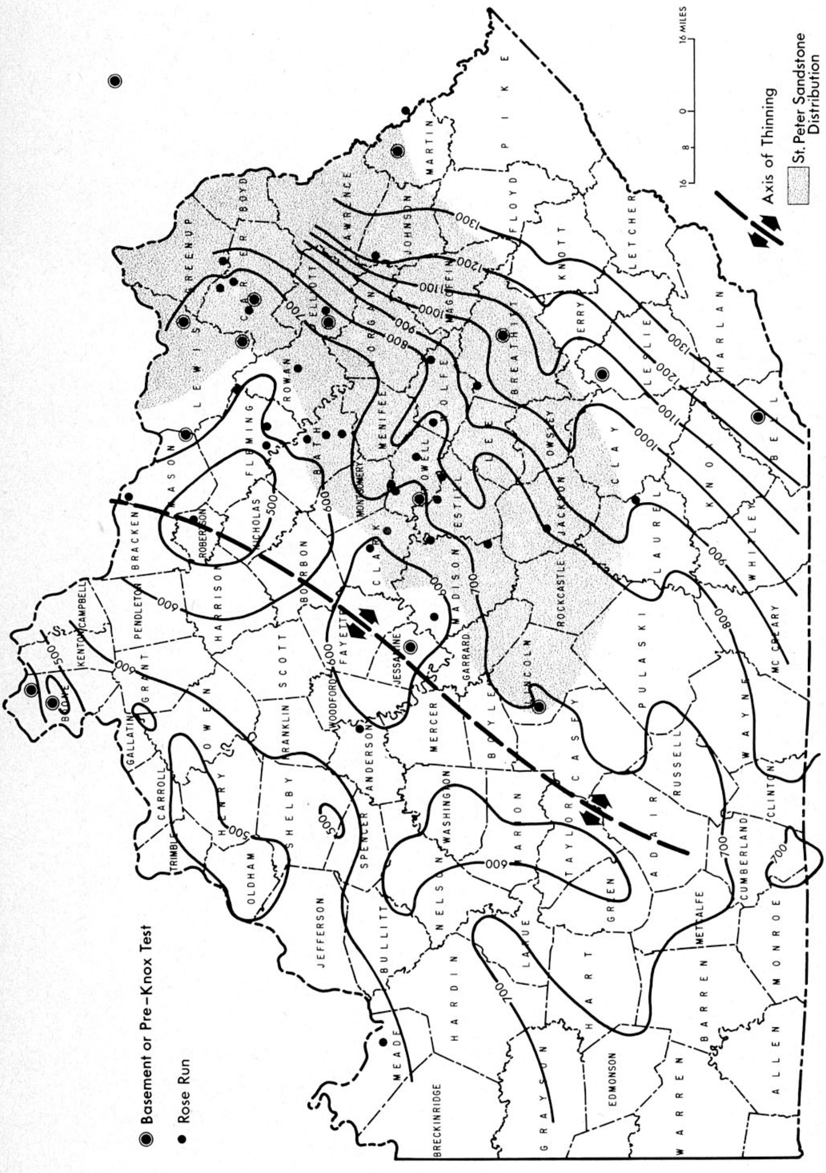


Fig. 2. Isopach map, top of Tyrone limestone to top of Knox Dolomite, showing axis of thinning over Cincinnati arch, and distribution of St. Peter Sandstone along east flank of the axis.

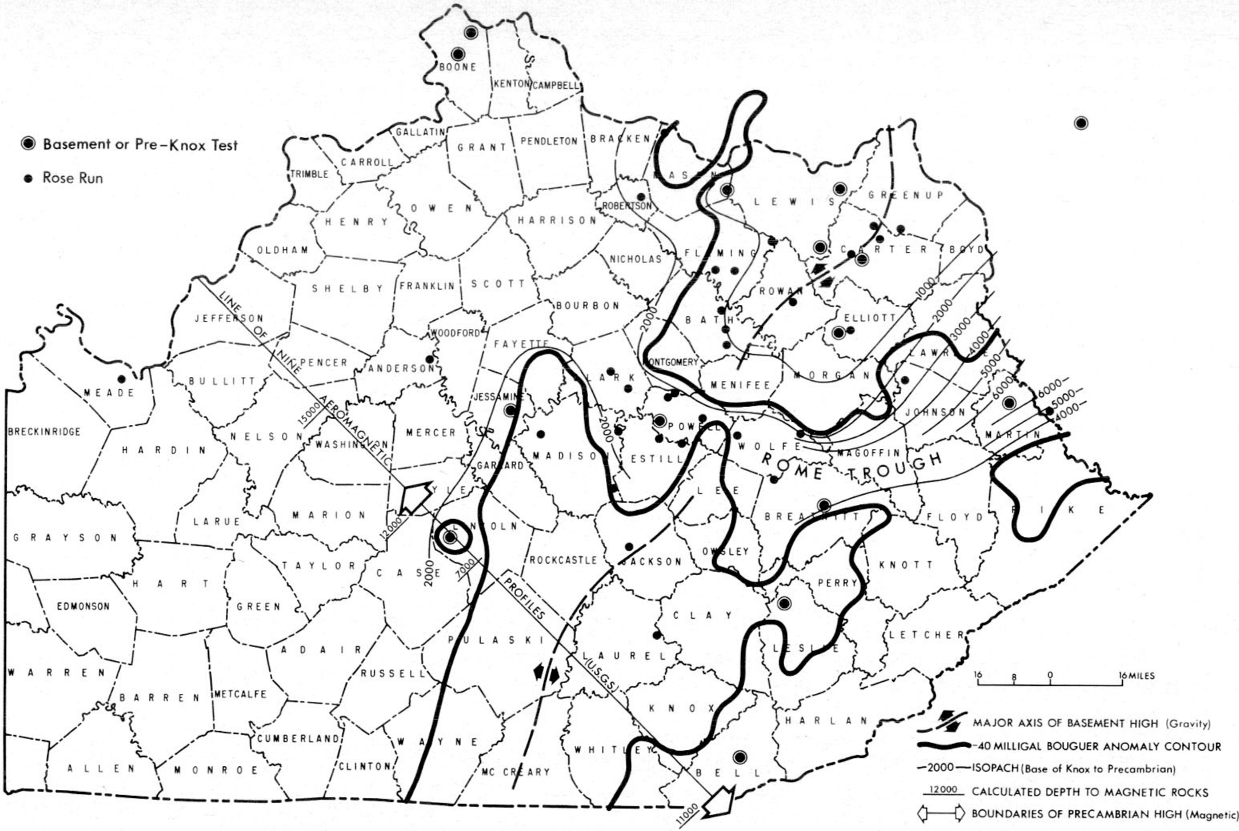


Fig. 3. Major Precambrian tectonic features, showing position of Rome trough south of the northeastern positive area.

derived from the sandy Beekmantown, and possibly from older exposed sediments to the north, were being deposited as St. Peter sandstone offshore from the positive area shown in Figure 1. As these sands were being deposited, the area to the west and northwest approximately coinciding with the present Cincinnati arch began to rise and became the dominant feature of eastern and central Kentucky. The St. Peter is thin to absent along this axis of Tyrone to Knox thinning, and becomes well developed in the area shown in Figure 2 along the east flank of the Middle Ordovician axis. The area of the Waverly arch became a broad shelf during the middle and late stages of St. Peter deposition. The St. Peter shoreline shifted westward toward the rising Cincinnati arch. An oscillating shoreline is indicated in the interbedding of St. Peter sandstone with dolomite, siltstone, and shale. The thickness and distribution of the St. Peter sandstone was controlled to a large extent by the amount of sand available. Where the Beekmantown in source areas was lacking in sand content or erosion was not extensive, very little sand was deposited even though shoreline conditions existed. The areas providing little sand usually coincide with the areas of thick Beekmantown. In general, in areas where the St. Peter is present the thickest sand development occurs where the Tyrone to Knox interval thickens. It should be noted here that the distribution of the St. Peter in eastern Kentucky coincides in general with the axis of a large gravity maximum. The significance of this is not yet clear.

CLARK AND ESTILL COUNTIES AREA

The regional southeast-dipping structure in the Clark and Estill Counties area is complicated by two major normal fault systems. The Irvine-Paint Creek and Kentucky River fault systems have an overall east-west trend. There is a suggestion of a northwest-southeast fault system coinciding with the trend of the Rome trough. Rapid thickening of the Knox and pre-Knox beds along a hinge line through Clark, Montgomery, Powell, and Menifee Counties can be seen on cross sections, isopachs, and gravity data. This thickening appears to be the result of downward displacement to the south and southwest, and truncation of the Upper Beekmantown to the northeast.

During St. Peter deposition a positive trend developed in a northwest-southeast direction through Clark and Powell Counties as shown on the large-scale Tyrone to Knox isopach (Plate 2 in envelope). The thinning shown on this isopach is probably depositional over an erosional high on the Knox surface. The northwest-southeast stratigraphic cross section (Fig. 4) through the No. 1 James Hall well in

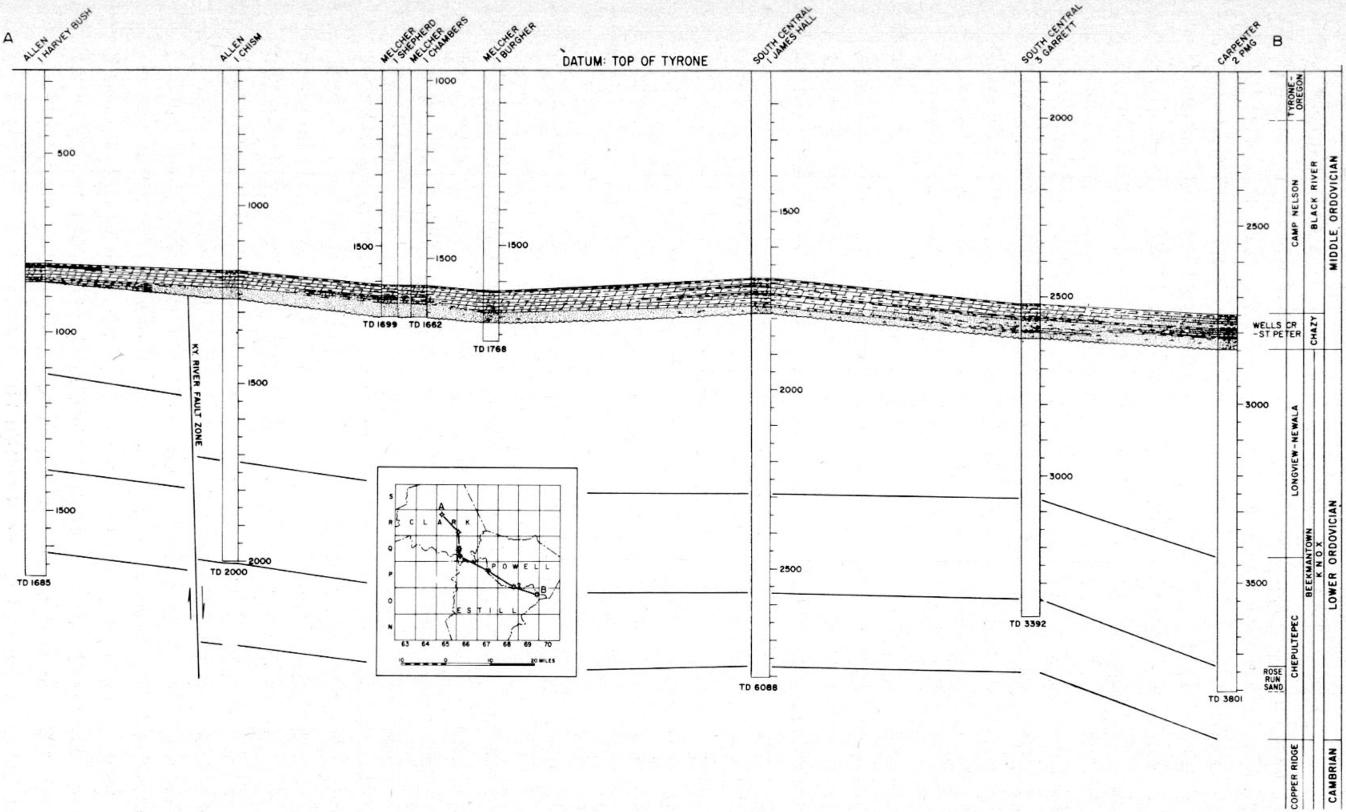


Fig. 4. Stratigraphic cross section, Clark, Estill, and Powell Counties, showing facies of Wells Creek-St. Peter, and thinning of St. Peter sand over the Knox high in Powell County.

Powell County illustrates the thinning of the St. Peter across this high. This Tyrone to Knox thinning is present today as a structural nosing.

The St. Peter sand is well-developed on both the northeast and southwest flanks of the thinning described above. The Furnace and Trapp St. Peter gas fields are located along the southwest flank where the sand is thick (50-60 feet) and well-developed. On the northeast flank of the high, the No. 1 Reddix well found thick (40 feet) St. Peter sand with good porosity and permeability, as evidenced by the 1200 feet of water fill-up. Wells drilled along the crest of the high have found the St. Peter to be thinner (18-30 feet) and tight.

The zero isopach of the St. Peter appears to extend northeast-southwest across Madison, Clark, Montgomery, Bath, and Fleming Counties. This line is defined by wells in Madison, Clark, and Fleming Counties, and, in general, parallels the Tyrone to Knox isopach (Fig. 1).

On the basis of present information it appears that reservoir conditions are best developed in areas of marked thickening of the St. Peter. Thick St. Peter sand development appears to coincide with thickening of the Tyrone to Knox interval.

FURNACE GAS FIELD

The Furnace gas field is located in Powell and Estill Counties as shown on the accompanying "Top of Knox" structure map (Plate 1, in envelope). Trapping conditions appear to be combination structural and stratigraphic. A structural trap is provided by closure against the Irvine-Paint Creek fault. The good sand development is a result of location on the flank of the post-Knox positive feature mentioned previously.

Sixteen productive wells were drilled in this field. The low B. T. U. value of the gas precluded its sale as commercial fuel, and it was used for repressuring the Lockport reservoir in Big Sinking oil field. Yearly production and shut-in pressure decline for the period 1950-1960 inclusive are shown on the accompanying graph, Figure 5. Monthly production for parts of 1953-1954 is shown for four additional wells, (Fig. 6).

Cumulative production to through 1960 was approximately 2 billion cubic feet of gas. Shut-in pressure decline from 750 psig to 100 psig indicates that the reservoir is nearly depleted.

In 1960 a well was drilled on the southeast flank of the field and the St. Peter was cored. The accompanying composite lithology, gamma ray-neutron, and core analysis (Fig. 7) shows the reservoir characteristics. This well pumped 3 BOPD and made approximately

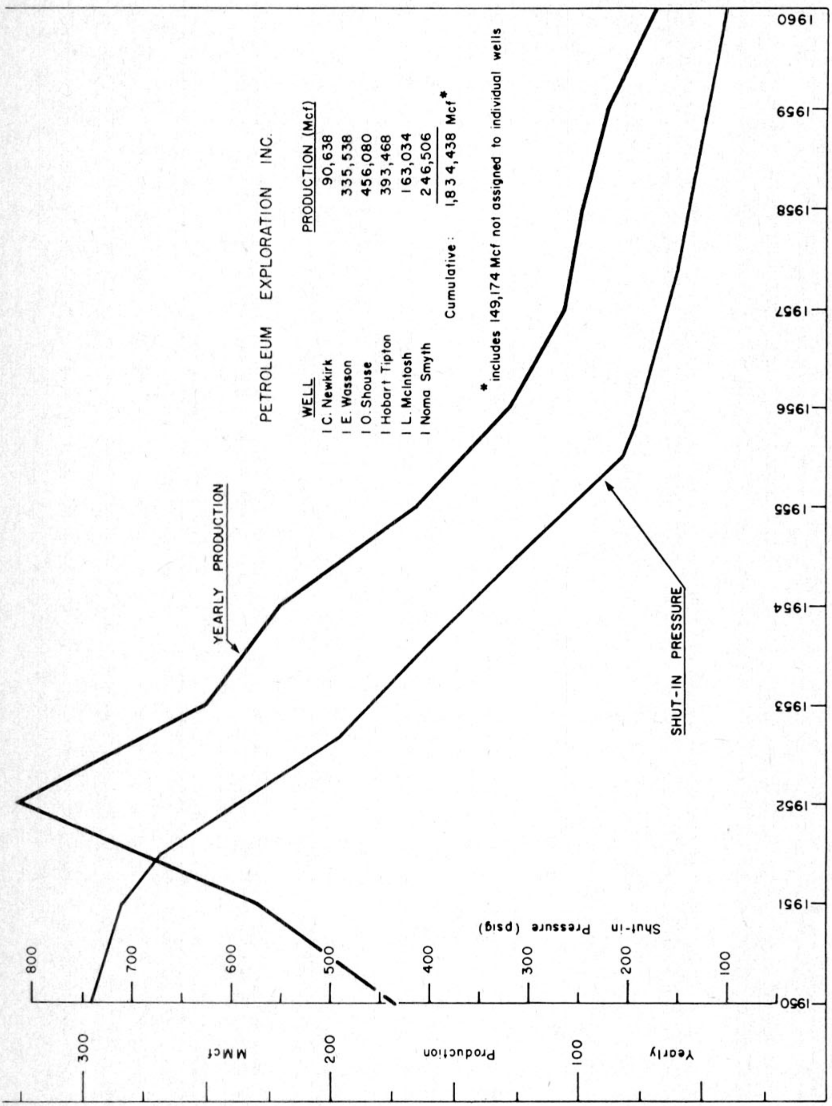


Fig. 5. Yearly gas production from St. Peter sand, Furnace gas field, 1950 to 1960, showing production of individual wells and decline of shut-in pressure.

100 Mcf of gas per day. It has since been plugged. Permeability in the main producing area was higher than that shown by the core analysis of the Nealy well, as evidenced by the much greater open flow potentials.

Selected gas analyses from the Furnace field are shown on the accompanying chart, (Fig. 8).

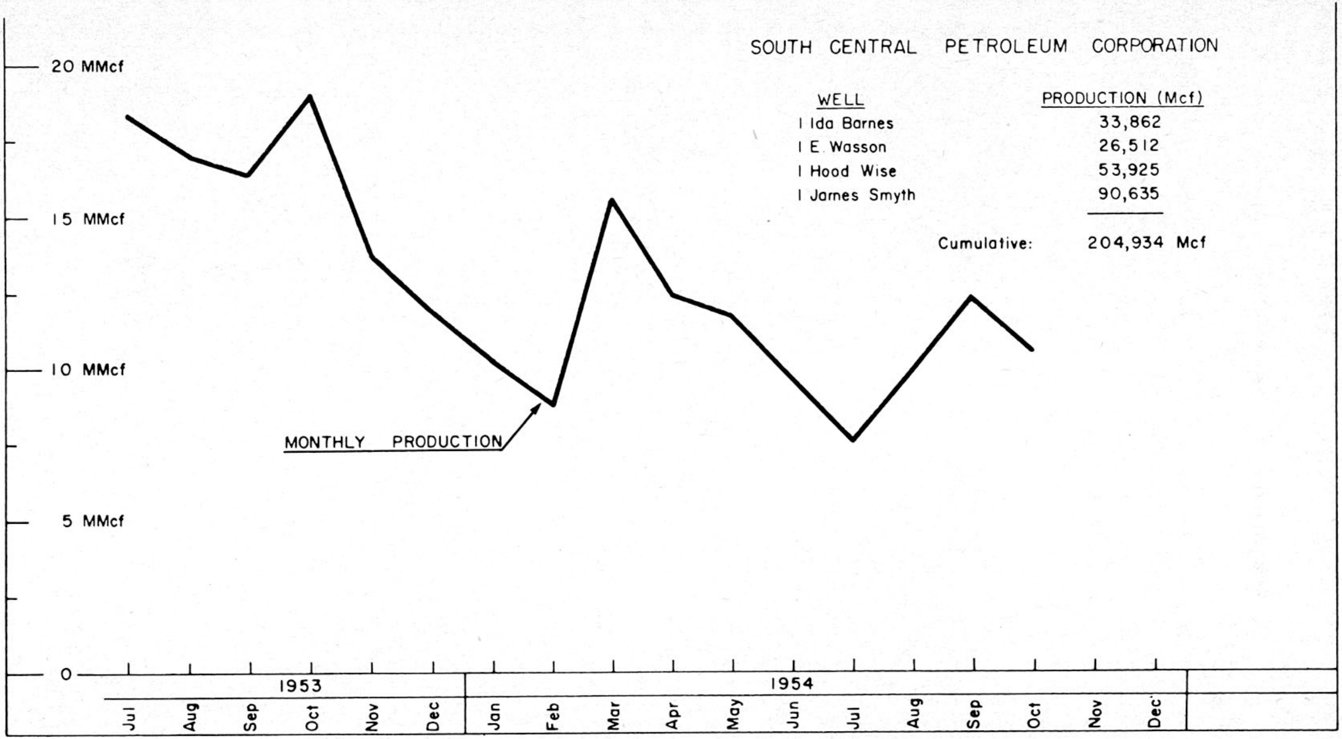


Fig. 6. Monthly gas production from St. Peter sand, four additional wells, Furnace gas field, 1953 and 1954. This production was marketed as fuel to a brick plant.

TRAPP GAS FIELD

The Trapp gas field is located in southeastern Clark County in 15-Q-66. The discovery well was the James Smith No. 1 Vernon Chambers, staked by Dr. W. R. Jillson. Production is from the St. Peter at an average depth of 1700 feet. Sand thickness in the area of the three productive wells is approximately 50 feet.

Martin Melcher and T. E. Atkins acquired the Chambers well and

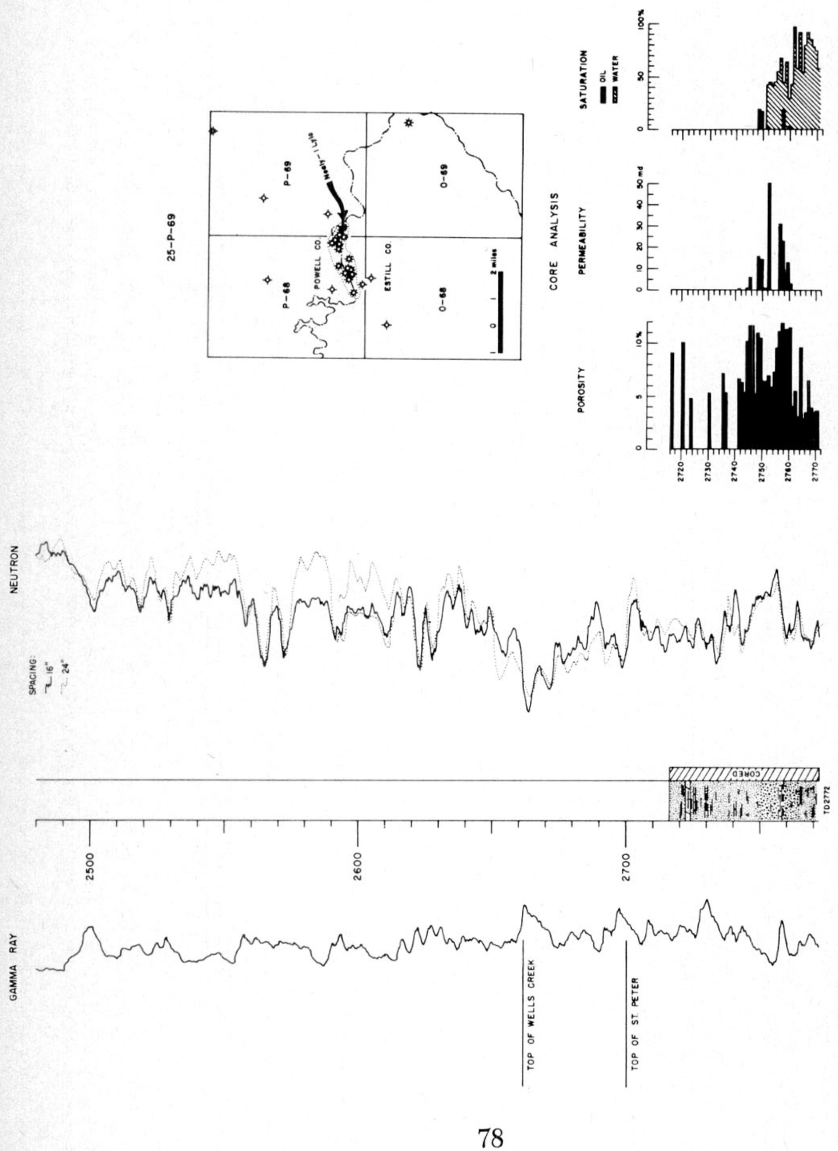


Fig. 7. Type log, Furnace gas field, showing lithology, gamma ray-neutron log, and core analysis of St. Peter Sandstone.

GAS ANALYSIS, FURNACE GAS FIELD
ESTILL AND POWELL COUNTIES

	PETX 1 L. McIntosh	PETX 1 C. Newkirk	CARPENTER 1 Hood Wise	CARPENTER - 3-A J. M. GARRETT 2560'-2563'	 2568'-2575'	 2600'-2604'	 2611'-2615'
Carbon Dioxide	25.54	37.60	41.04	18.2	34.9	40.9	41.95
Hydrogen Sulfide	Nil	Nil	0.56	Nil	Nil	0.50	0.55
Nitrogen	1.44	2.04	2.28				
Methane	69.93	57.88	54.68	67.45	59.05	54.0	53.04
Ethane	1.79	1.14	0.95				
Propane GPM	0.70 0.192	0.42 0.115	0.23				
ISO-Butane GPM	0.10 0.033	0.07 0.023	0.04				
N-Butane GPM	0.25 0.079	0.14 0.044	0.10				
ISO-Penatane GPM	0.09 0.033	0.12 0.044	0.04				
N-Pentane GPM	0.07 0.025	0.13 0.047	0.01				
Hexane Plus GPM	0.09 0.039	0.46 0.196	0.07				
Specific Gravity 1 2	0.8325 0.8347	0.9558		0.7944	0.9295	0.9813	0.9862
BTU[3] 1 2	765 758	646		764	643	572	566
Mercaptan Sulphur	5.63gr/100 SCF	5.02fr/100 SCF		5.48gr/100 SCF	2.81fr/100 SCF	2.33gr/100 SCF	6.21gr/100 SCF
Certificate No.*	15,757	15,758		13,782	13,780	13,783	13,781
Date	1/23/50	1/23/50		3/12/49	3/12/49	3/12/49	3/12/49

*E.W. Saybolt & Co.
Prodbielnaik Analysis

1 Air free basis
2 Determined as received
3 Per SCF (saturated) at 60° F, 760 mm Hg

GAS ANALYSIS (Mol %)

Fig. 8. Gas analyses, Furnace gas field, showing high percentage of CO_2 and low BTU of gas.

drilled three additional wells, two of which were producers. The No. 1 Burgher was a 1½ mile step-out to the south and was dry, with a show of oil and gas after frac. Kentucky Drilling & Operating Corporation is presently drilling a one-mile step-out to the east.

Trapping conditions are believed to be combination structural and stratigraphic. Structural nosing and updip faulting combined with thick sand development in a regional Tyrone to Knox thickening are the controlling factors.

Reservoir characteristics are shown on the composite of type logs from the Melcher No. 1 Barrett well, (Fig. 9).

Open flow potentials and shut-in pressures are shown on the accompanying graph, (Fig. 10).

Reserves are calculated at approximately 650 MMcf per 160-acre location, using 20 feet of net pay.

All wells have been sand-water fractured using up to 15,000 pounds of sand and 15,000 gallons of water. Breakdown pressure for open-hole frac is approximately 2000 psi.

Extent of the productive area has not yet been determined.

CONCLUSIONS

Possibilities of finding additional production in the St. Peter sand in Clark and Estill Counties appear to be best along the axis and flanks of maximum St. Peter sand development. The most reliable guide to thick sand development appears to be the Tyrone to Knox isopach.

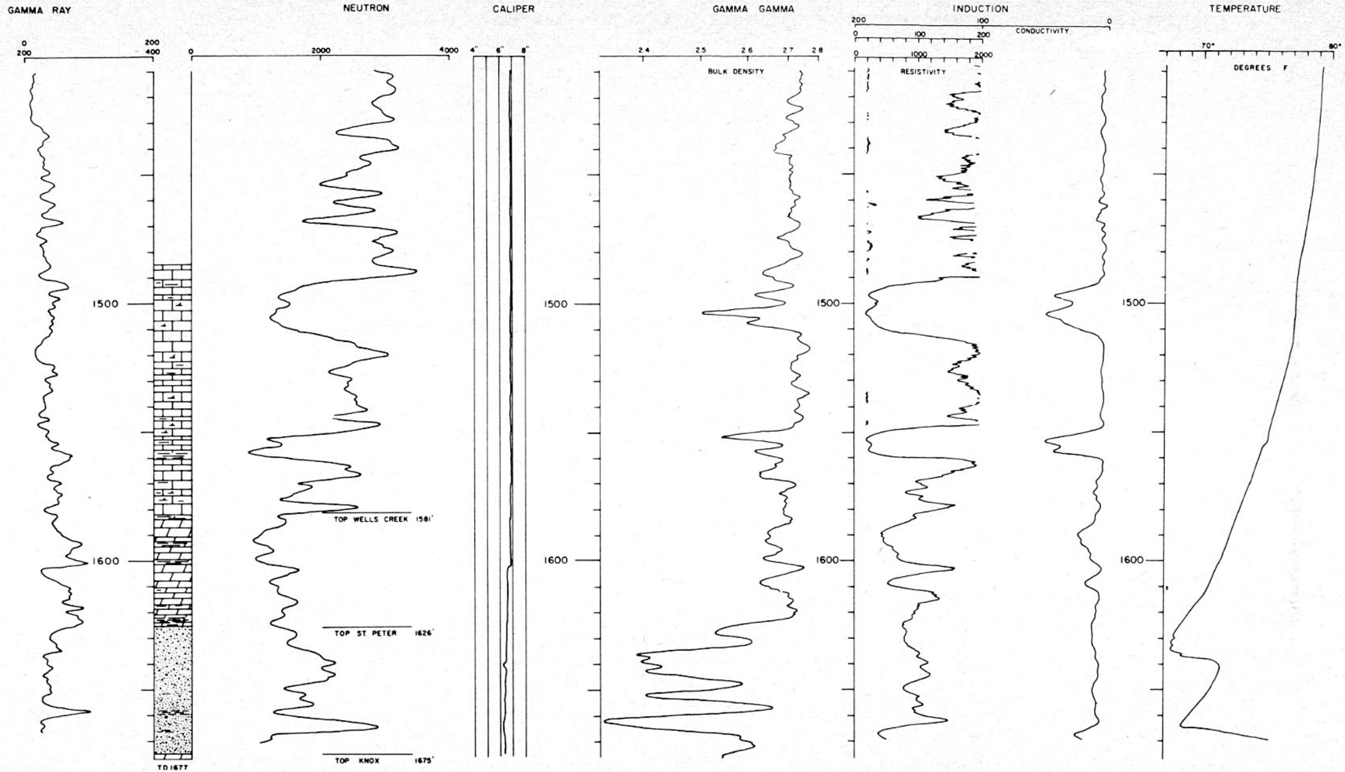


Fig. 9. Type logs, Trapp gas field; reservoir characteristics of St. Peter Sandstone shown by composite of logs from Martin Melcher No. 1 Barrett well.

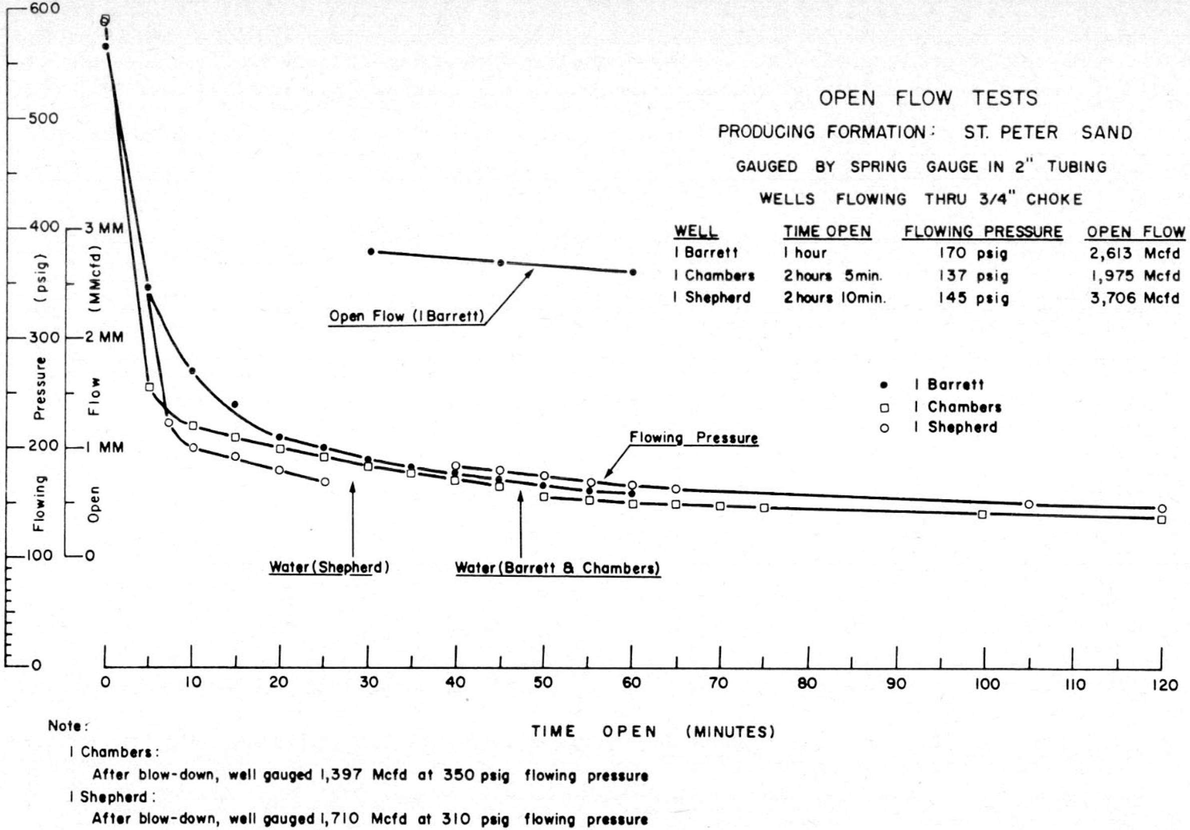


Fig. 10. Open flow potentials, Trapp gass field, showing shut-in pressures, and flowing pressures during tests.

COMPLETION TECHNIQUES AND RESULTS OF RECENT BEREA SAND DEVELOPMENT IN PIKE COUNTY, KENTUCKY

GEORGE R. THOMAS, Geologist
J. B. LAUFFER, Engineer
United Fuel Gas Company
Prestonsburg, Kentucky

ABSTRACT

During the past four years the development of considerable gas reserves in the Berea sand formation of Pike County, Kentucky, has been the result of the application of new completion methods. This development has seen the advent of the density log and air cementing practices. "Set through" completions and hydraulic fracturing are now common practice in Berea sand production. The average Berea sand well has only a show of gas before, and 660 MCF open flow after fracture treatment. Well spacing is currently on approximately 200 acres and reserves are calculated to be 2.3 MMCF per acre. "Pay out" time on the average Berea well should be from five to seven years, although only limited production history is available to date.

These new completion practices may extend Berea sand production to western Pike County and possibly to other sections of eastern Kentucky.

INTRODUCTION

During the past four years the development of considerable gas reserves in the Berea sand formation of Pike County, Kentucky, has been the result of the application of new completion techniques.

This paper will cover only the southeastern section of Pike County shown on plate 1 (in envelope). By utilizing hydraulic fracturing, 54 wells have been completed in this area in the Berea sand. As may be noted in the index of this map, 10 of these wells were completed using "open hole" methods and 44 were completed with the "set through" method. With the exception of one well, which had half a million cubic feet of gas natural before treatment, the "open hole" versus "set through" completion method speaks for itself.

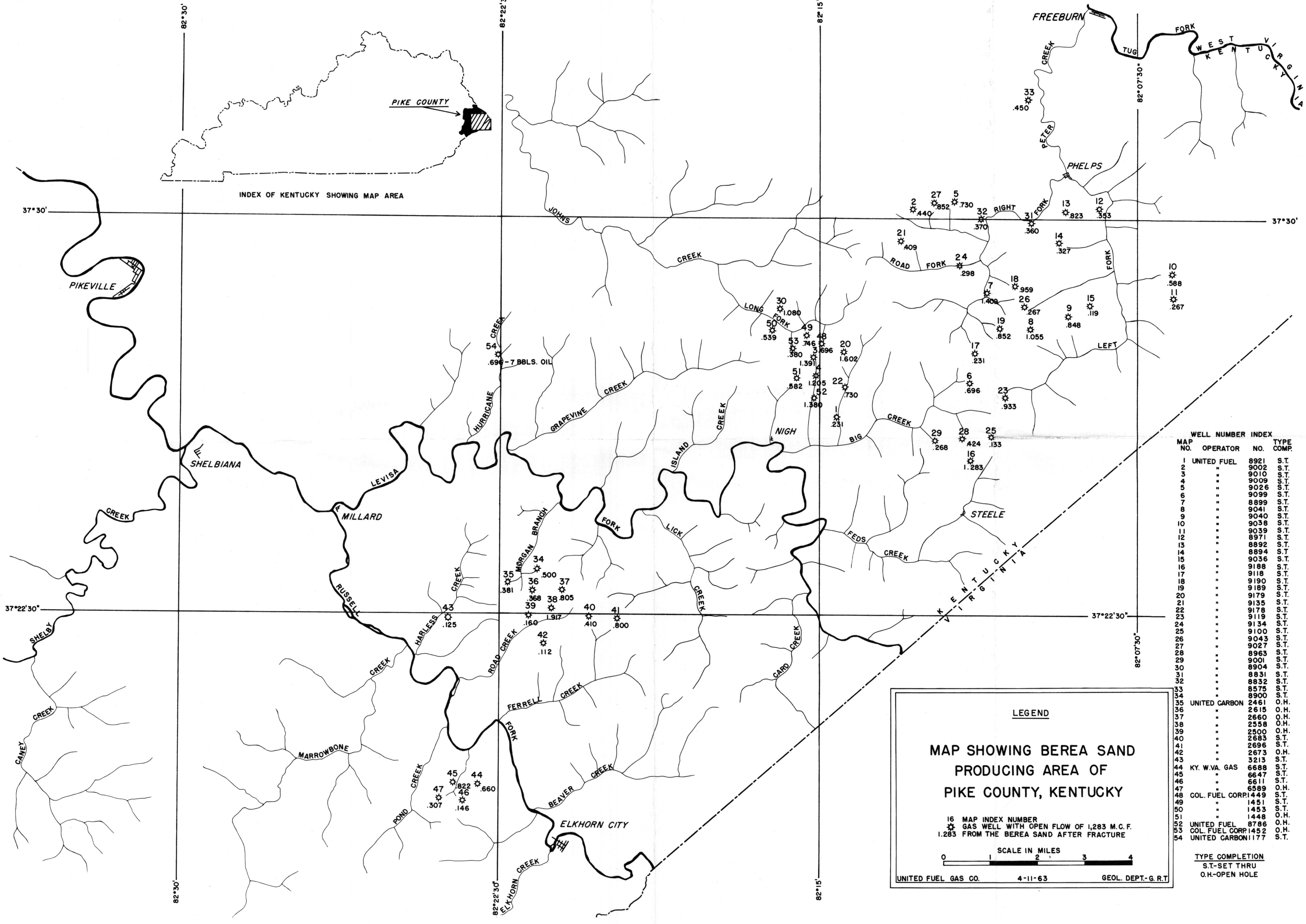
It is the writers' opinion that production figures on these wells will have similar comparisons, in that the "set through" completion will deliver nearly twice the gas as the "open hole" completion.

It is too early to prove this with production figures since the only sustained production records available are on "open hole" completions.

The open flows shown on the map (pl. 1) were taken from the various company well records as their final test.

GEOLOGY

The Berea sand in Pike County ranges in thickness from 10 to 130 feet with a thin area located at the juncture of the states of Kentucky,



WELL NUMBER INDEX

MAP NO.	OPERATOR	NO.	TYPE COMP.
1	UNITED FUEL	8921	S.T.
2	"	9002	S.T.
3	"	9010	S.T.
4	"	9009	S.T.
5	"	9026	S.T.
6	"	9099	S.T.
7	"	8899	S.T.
8	"	9041	S.T.
9	"	9040	S.T.
10	"	9038	S.T.
11	"	9039	S.T.
12	"	8971	S.T.
13	"	8892	S.T.
14	"	8894	S.T
15	"	9036	S.T.
16	"	9188	S.T.
17	"	9118	S.T.
18	"	9190	S.T.
19	"	9189	S.T.
20	"	9179	S.T.
21	"	9135	S.T.
22	"	9178	S.T.
23	"	9119	S.T.
24	"	9134	S.T.
25	"	9100	S.T.
26	"	9043	S.T.
27	"	9027	S.T.
28	"	8963	S.T.
29	"	9001	S.T.
30	"	8904	S.T.
31	"	8831	S.T.
32	"	8832	S.T.
33	"	8575	S.T.
34	"	8900	S.T.
35	UNITED CARBON	2461	O.H.
36	"	2615	O.H.
37	"	2660	O.H.
38	"	2558	O.H.
39	"	2500	O.H.
40	"	2683	S.T.
41	"	2696	S.T.
42	"	2673	O.H.
43	"	3213	S.T.
44	KY. W.VA. GAS	6688	S.T.
45	"	6647	S.T.
46	"	6611	S.T.
47	"	6589	O.H.
48	COL. FUEL CORP.	1449	S.T.
49	"	1451	S.T.
50	"	1453	S.T.
51	"	1448	O.H.
52	UNITED FUEL	8786	O.H.
53	COL. FUEL CORP.	1452	O.H.
54	UNITED CARBON	1177	S.T.

TYPE COMPLETION
S.T.-SET THRU
O.H.-OPEN HOLE

West Virginia, and Virginia. In this area a post-Devonian high has either restricted sand deposition or the sand has been eroded after deposition or a combination of both. The gradual and uniform thickening of sand to the west (see plate 2, in envelope) has produced a favorable stratigraphic condition for the accumulation of hydrocarbons. A similar sand condition also exists to the east of this "high" in southern West Virginia.

The source of Berea gas in this area is probably from the carbonaceous shales of the Sunbury, lying directly above the sand, and the Devonian "Brown Shale" lying directly below the sand.

In the area of southern Pike County, the Berea is a fine sandstone containing much siltstone and shale. Clean sand zones within this generally argillaceous section contain gas reservoirs which respond well to shooting and hydraulic fracturing.

Both vertical and horizontal fractures occur naturally in the Berea sand as observed on outcrop and in cores taken from eastern Kentucky.

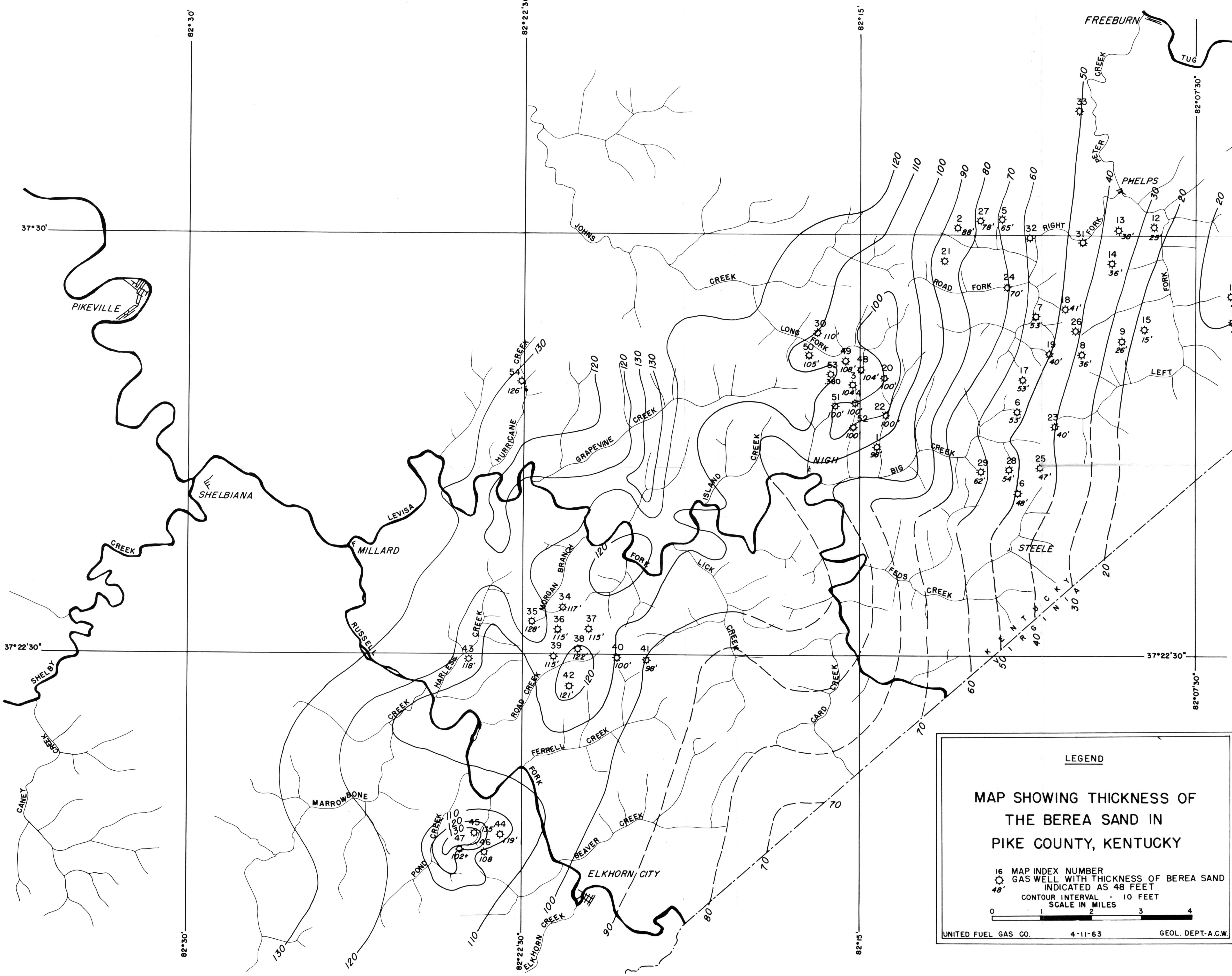
Several attempts to core the Berea sand in Pike County, using air as a circulating medium, have failed. Cores of the pay section are not available from this area, and therefore, all porosities are determined from density logs. These porosity calculations range from 8 to 15 percent in the pay zones and average about 10 percent. However, production data from these wells indicate that these porosity calculations may be too low. Density logs are calculated in the Berea using an average grain density of 2.70 grams per CC. This grain density may be as high as 2.78 or 2.80 in some porous zones, depending upon the cementing material between the sand grains. A calcareous or dolomitic cement could raise the grain density count considerably and thus give much higher porosity determinations.

Plate 3 (in envelope) is a structure map of southeastern Pike County drawn on top of the Berea sand. The structural trend is a regional monocline with dip to the southeast, interrupted with only minor irregularities. It is evident that present structure has little or no bearing on gas production from the Berea sand in this area.

COMPLETION PRACTICES

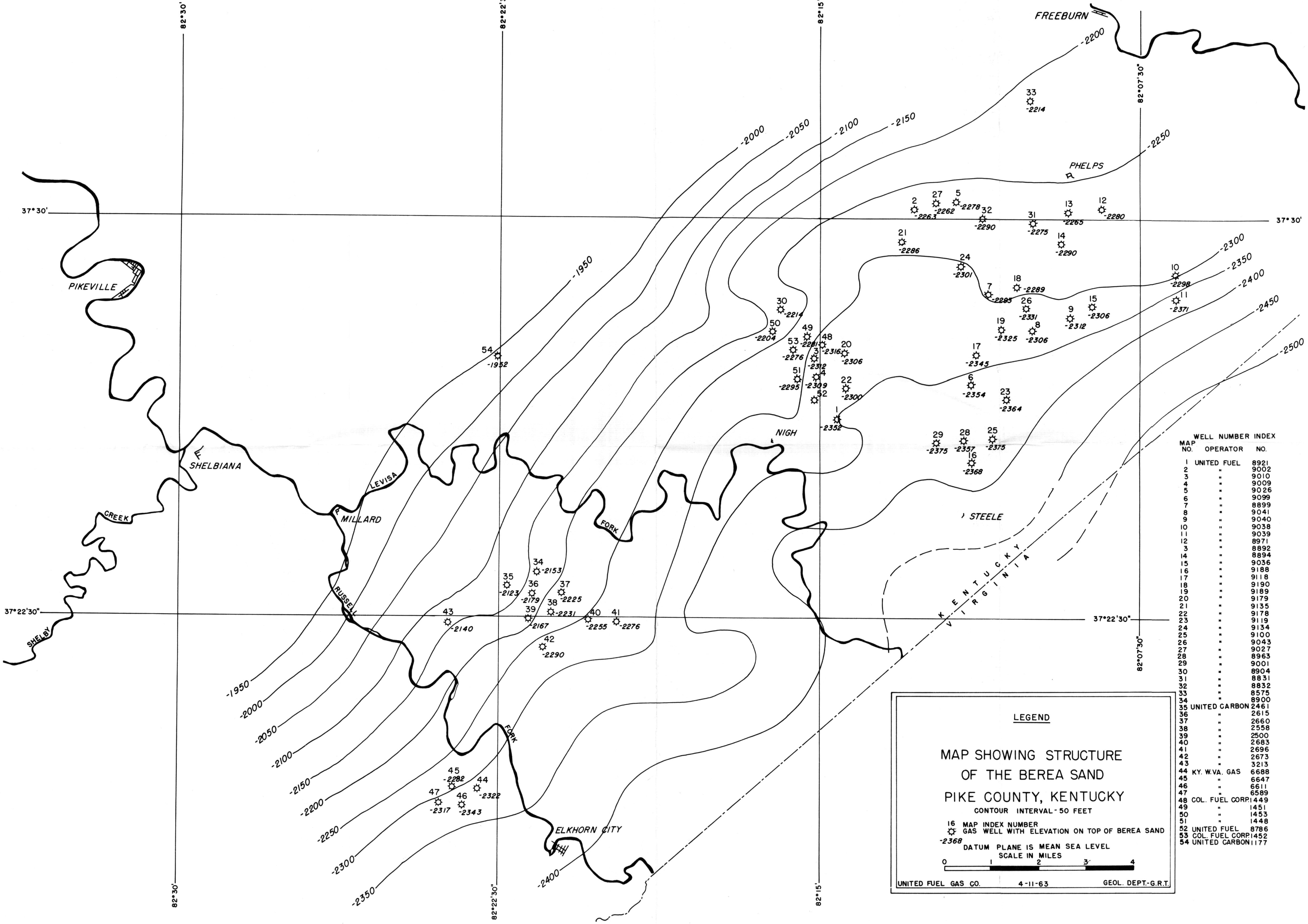
Common completion practice in the Berea sand in Pike County, Kentucky, had been to shoot the Berea with the "Brown Shale" section or to fracture the Berea through open hole packers or to set casing on top of the sand and fracture open hole. The results of this type well completion have been somewhat discouraging. However, through the use of new completion techniques recently applied to this area, many Berea sand wells have been successfully completed.

Thomas and Lauffer, Plate 2
Ky. Geol. Survey, Spec. Pub. 8, 1964



WELL NUMBER INDEX

MAP NO.	OPERATOR	NO.
1	UNITED FUEL	8921
2	"	9002
3	"	9010
4	"	9009
5	"	9026
6	"	9099
7	"	8899
8	"	9041
9	"	9040
10	"	9038
11	"	9039
12	"	8971
13	"	8892
14	"	8894
15	"	9036
16	"	9188
17	"	9118
18	"	9190
19	"	9189
20	"	9179
21	"	9135
22	"	9178
23	"	9119
24	"	9134
25	"	9100
26	"	9043
27	"	9027
28	"	8963
29	"	9001
30	"	8904
31	"	8831
32	"	8832
33	"	8575
34	"	8900
35	UNITED CARBON	2461
36	"	2615
37	"	2660
38	"	2558
39	"	2500
40	"	2683
41	"	2696
42	"	2673
43	"	3213
44	KY. W. VA. GAS	6688
45	"	6647
46	"	6611
47	"	6589
48	COL. FUEL CORP.	1449
49	"	1451
50	"	1453
51	"	1448
52	UNITED FUEL	8786
53	COL. FUEL	1452
54	UNITED CARBON	1177



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51	"	1448
52	UNITED FUEL	8786
53	COL. FUEL CORP.	1452
54	UNITED CARBON	1177

Production figures compiled to date indicate these new completion techniques to be economically feasible.

Sucessful well completions in the Berea depended upon the solving of two major problems: selecting the proper logging program; and eliminating the loss of circulation of mud and cement to the fractured shale zones above the pay, while cementing a string of casing through the Berea sand.

The proper logging program was developed with the introduction of the so-called "dry hole" logs (fig. 1). These logs (Density, Gamma Ray, and Induction) were designed to be run in an empty hole or a gas well that contains little or no fluid. These logs can be used effectively for good stratigraphic correlation, accurate porosity determination and water saturation.

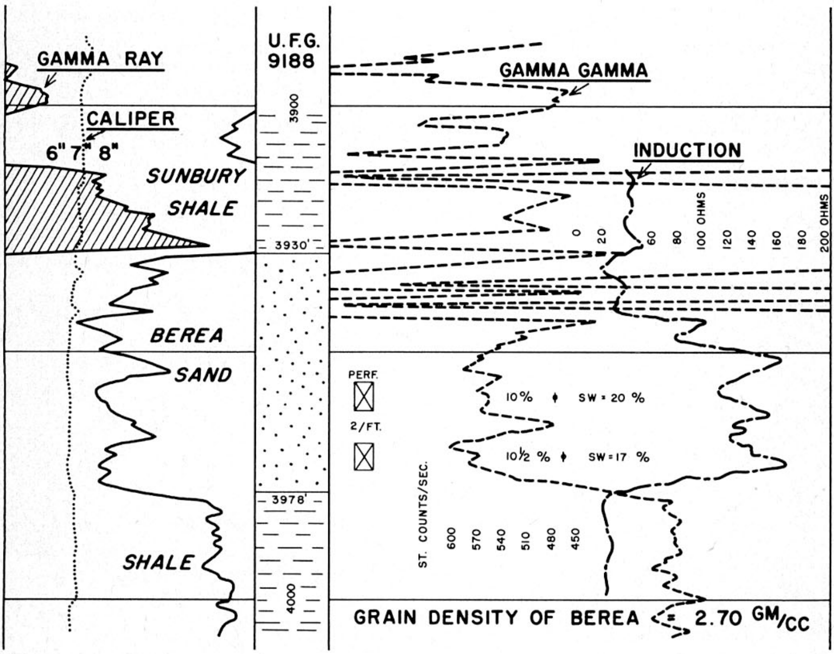

Fig. 1. Typical family of logs run in Pike County, Kentucky.

The loss of circulation problem has been greatly reduced by the use of better conditioned muds containing lost circulation material or by the use of air, natural gas, or inert gases to replace mud as a circulating medium. Using gas as a circulating medium prior to cementing reduces the hydrostatic pressures created against the weak formations near the bottom of the hole. This new cementing process was developed and is being patented by United Fuel Gas Company.

At the present time the major problem is to contain the fracture within the sand body and thus extend the reservoir drainage area.

Berea sand wells in Pike County are drilled into the top of the "Big Lime" formation, which is usually from 2500 to 3000 feet in depth, where 7-inch casing is run, and a 6 ½-inch hole is drilled to approximately 50 feet below the Berea sand, at depths of from 3500 to 4000 feet. The well is then logged with Gamma Ray, Density, and Induction logs. A careful study of these logs, coupled with the microscopic examination of the drill cuttings is utilized to determine the zones to be perforated. A string of 4 ½-inch (11.6 lb) casing is run through the producing formation to within a few feet of the bottom of the hole. The casing is assembled in the following manner:

A. A guide shoes with side port openings is run on the bottom of the casing.
B. A 10 to 15 foot "pup joint" is run with a 6½ x 4½" (slim hole) centralizer.
C. A positive seal float collar is placed on top of the "pup joint."
D. Three or four full length joints of casing are run with a centralizer secured to the third or fourth joint.
E. A right-left nipple is run about 12 joints up for safety.

The 4 ½-inch casing is usually cemented with a total of 40 cubic feet of pozzolan cement containing an accelerator. The cemented interval in the annulus averages from 325 to 350 feet.

In planning a fracture treatment, there are nine points which have to be considered:

1. Gathering and selecting the required well data.
2. Predicting the inclination of the fracture plane (horizontal or vertical).
3. Determining the fracture conductivity (a measure of the resistance to flow of the reservoir fluids through the reservoir and created fracture).
4. Estimating the fracture area and the penetration desired.
5. Calculating coefficients of the fracturing fluids being considered.
6. Selecting the injection rate and size of the treatment.
7. Determining the horsepower required.
8. Estimating the number of perforations accepting fluid.
9. Comparing the economics of different fracturing treatments. (See Dowell, Inc., Frac Guide.)

After the zones to be treated have been determined, the perforating of the production string is carried out. The number, type, and size of the perforations depends on the total thickness of the zone to be perforated. Also, the selection of perforations are controlled by the projected treating pressures and injection rates of fluid and sand into

Thomas and Lauffer, Plate 4
Ky. Geol. Survey, Spec. Pub. 8, 1964

STATISTICS OF BEREA SAND WELLS FRACTURED BY UNITED FUEL GAS COMPANY IN PIKE COUNTY, KENTUCKY DURING 1961 AND 1962

	U.F.G.CO. WELL NO.	ELEVATION	TOTAL NO. OF PERFORATIONS	AVERAGE TREATING PRESSURE	AVERAGE FLUID INJECTION RATE	AVERAGE SAND INJECTION RATE	TOTAL SAND USED POUNDS	TOTAL WATER USED GALLONS	OPEN FLOW BEFORE TREATMENT MCF	OPEN FLOW AFTER TREATMENT MCF	10 MINUTE PICKUP POUNDS	POROSITY %	PAY THICKNESS FEET
							WELLS COMPLETED IN 1961						
1.	8921	1022.2	*1 Frac Initiator	800	19.0	1.50	30,000	20,000	0	231	35	10.0	17
2.	9002	1539.81	26	900	30.9	1.00	18,000	18,984	0	440	75	8.5	19
3.	9010	1550.93	46	1700	60.1	2.00	80,000	42,000	0	1,391	240	11.5	17
4.	9009	1216.34	42	550	45.0	1.33	35,000	23,000	0	1,205	210	8.5	18
5.	9026	1870.77	26	500	38.0	1.50	24,000	18,942	0	730	150	10.0	18
6.	9099	1442.47	28	950	38.0	1.40	42,000	30,744	0	696	194	8.5	14
7.	8899	1168.1	18	700	41.0	1.70	44,000	26,250	0	1,409	260	10.2	17
8.	9041	1816.27	*2 Frac Initiators	2250	32.0	1.00	15,000	15,000	622	1,055	140	15.0	8
9.	9040	2043.90	14	650	39.0	.75	15,000	21,000	26	848	160	11.0	12
10.	9038	1447.37	*1 Frac Initiator	1400	26.0	1.50	30,000	20,160	25	588	147	13.0	7
11.	9039	1089.52	*1 Frac Initiator	1250	32.0	1.77	30,000	17,262	19	267	130	10.5	8
12.	8971	941.50	26	2700	16.0	.86	6,000	7,000	0	353	150	11.0	6
13.	8892	1061.72	51	1400	34.0	2.00	50,000	26,040	15	823	115	9.5	17
14.	8894	1341.69	26	1750	30.0	1.66	25,000	15,120	0	327	85	9.0	20
15.	9036	1352.16	*1 Frac Notch	1000	30.0	1.90	40,000	22,050	0	119	60	8.5	8
	TOTAL		423	18500	511.0	21.87	484,000	323,552	707	10,482	1,951	154.7	206
	AVERAGE		28.2	1233	34.1	1.46	32,000	21,500	47	700	130.5	10.3	14
	* 1 Frac Initiator = 20 Capsule Jets												
							WELLS COMPLETED IN 1962						
16.	9188	1559.03	26	980	41.5	1.75	60,000	34,482	0	1,283	305	10.0	17
17.	9118	1455.20	28	1400	53.0	2.12	54,000	25,536	0	231	150	8.0	17
18.	9190	1365.01	33	1500	69.7	1.62	60,000	36,918	0	959	253	11.5	15
19.	9189	1453.03	33	1350	48.7	1.77	58,000	32,718	0	852	200	9.0	14
20.	9179	1736.25	32	1200	56.1	1.61	45,000	28,266	0	1,602	300	9.9	28
21.	9135	1693.42	22	1840	52.5	2.50	70,000	27,678	0	409	155	10.5	17
22.	9178	1114.51	30	1000	35.0	2.00	45,000	22,890	0	730	170	9.0	17
23.	9119	1633.65	31	1000	35.0	1.21	15,000	12,390	0	933	208	10.5	17
24.	9134	1085.34	29	1350	65.1	2.00	65,000	32,298	0	298	102	9.5	16
25.	9100	2173.34	16	1075	38.0	1.50	36,000	24,696	0	133		8.0	14
26.	9043	1443.57	27	1400	39.1	1.89	34,000	18,396	0	267	42	10.5	10
27.	9027	1692.22	31	700	40.0	1.60	40,000	25,032	0	852	165	11.0	17
28.	8963	1397.95	30	1250	33.0	1.50	30,000	20,286	0	424		10.5	16
29.	9001	1437.18	20	750	36.0	2.00	45,000	22,682	0	268		8.0	12
	TOTAL		388	16795	642.7	23.07	657,000	364,266	0	9,241	1,745	135.0	227
	AVERAGE		27.7	1200	45.9	1.64	46,000	26,000	0	660	186.3	9.6	16

NOTE: All wells are "set through" type completions.

HYDRAULIC FRACTURE INJECTION RATES

Proposed fracturing treatment tables for a well completed at a depth of 4,000 feet with 4½" O.D. J-55 casing as the production casing, using water as the fracturing medium and a C_w or the fluid coefficient of wall building fluids equal to 2.9 to 3.2 feet per square root of minutes with an assumed bottom hole temperature of 80 degrees Fahrenheit. (With the various fracturing treatment variables listed below).

	20,000 Gallons of Slick Water			40,000 Gallons of Slick Water			60,000 Gallons of Slick Water		
SURFACE TREATING PRESSURE P.S.I.	AVERAGE SAND INJECTION RATE POUNDS PER GALLON	TOTAL SAND REQUIREMENT IN 20-40 MESH POUNDS	FRACTURE AREA SQUARE FEET	AVERAGE SAND INJECTION RATE POUNDS PER GALLON	TOTAL SAND REQUIREMENT IN 20-40 MESH POUNDS	FRACTURE AREA SQUARE FEET	AVERAGE SAND INJECTION RATE POUNDS PER GALLON	TOTAL SAND REQUIREMENT IN 20-40 MESH POUNDS	FRACTURE AREA SQUARE FEET
Injection Rate 40 Barrels of Fracturing Fluid Per Minute									
2500	1.598	31,960	37,600	1,254	50,150	59,000	1.125	67,490	79,400
2400	1.611	32,215	37,900	1,275	51,000	60,000	1,129	67,745	79,700
2300	1.619	32,385	38,100	1,290	51,595	60,700	1.133	68,000	80,000
2200	1.630	32,595	38,300	1,294	51,765	60,900	1,136	68,170	80,200
2100	1.632	32,640	38,400	1,298	51,935	61,100	1.139	68,340	80,400
2000	1.637	32,725	38,500	1,303	52,105	61,300	1.142	68,510	80,600
1900	1.641	32,810	38,600	1,306	52,225	61,500	1.143	68,595	80,700
1800	1.649	32,980	38,700	1,308	52,310	61,600	1.146	68,765	80,900
1700	1.658	33,150	38,900	1,316	52,650	61,700	1.150	69,020	81,200
1600	1.666	33,320	39,100	1,323	52,905	62,100	1.156	69,275	81,500
1500	1.675	33,490	39,300	1,333	53,330	62,400	1.171	70,210	81,700
1400	1.683	33,660	39,500	1,342	53,670	62,900	1.184	71,060	82,800
1300	1.704	34,085	40,000	1,350	54,010	63,300	1.199	71,910	83,800
1200	1.721	34,425	40,400	1,359	54,350	63,700	1.210	72,605	84,500
1100	1.738	34,765	40,800	1,374	54,945	64,100	1.219	73,165	85,100
1000	1.765	35,290	41,300	1,389	55,540	64,800	1,224	73,420	85,400
* 900	1.774	35,460	41,500	1,401	56,050	65,500	1,229	73,760	85,800
800	1.786	35,715	41,800	1,414	56,560	66,100	1,235	74,100	86,200
700	1.810	36,225	42,400	1,429	57,175	66,800	1,251	75,035	87,300
Injection Rate 50 Barrels of Fracturing Fluid Per Minute									
2500	1.717	34,340	40,400	1.403	56,100	66,000	1,233	73,950	87,000
2400	1.726	34,510	40,600	1.407	56,270	66,200	1,234	74,035	87,100
2300	1.751	35,020	41,200	1.409	56,355	66,300	1,237	74,205	87,300
2200	1.760	35,190	41,400	1.413	56,525	66,500	1,240	74,375	87,500
2100	1.785	35,700	42,000	1.420	56,780	66,800	1,242	74,545	87,700
2000	1.794	35,870	42,200	1.424	56,950	67,000	1,247	74,800	88,000
1900	1.798	35,955	42,300	1.426	57,035	67,100	1,251	75,055	88,300
1800	1.806	36,125	42,500	1.430	57,205	67,300	1,257	75,395	88,700
1700	1.815	36,295	42,700	1.451	58,055	68,300	1,264	75,825	89,200
1600	1.823	36,465	42,900	1.473	58,905	69,300	1,285	77,095	90,700
1500	1.849	36,975	43,500	1.492	59,670	70,200	1,298	77,860	91,600
1400	1.866	37,315	43,900	1.502	60,095	70,700	1,310	78,625	92,500
1300	1.879	37,570	44,200	1.513	60,520	71,200	1,318	79,050	93,000
1200	1.904	38,080	44,800	1.524	60,945	71,700	1,327	79,645	93,700
* 1100	1.934	38,675	45,500	1.534	61,370	72,200	1,346	80,750	95,000
1000	1.964	39,270	46,200	1.551	62,050	73,000	1,361	81,685	96,100
900	2.023	40,460	47,600	1.573	62,900	74,000	1,377	82,620	97,200
Injection Rate 60 Barrels of Fracturing Fluid Per Minute									
2500	1.921	38,420	45,200	1.566	62,645	73,700	1.388	83,300	98,000
2400	1.934	38,675	45,500	1.573	62,900	74,000	1.394	83,640	98,400
2300	1.951	39,015	45,900	1.590	63,580	74,800	1,401	84,065	98,900
2200	1.985	39,651	46,700	1.613	64,515	75.900	1,408	84,490	99,400
2100	1.989	39,780	46,800	1.617	64,685	76,100	1,414	84,830	99,800
2000	2.001	40,035	47,100	1.621	64,855	76,300	1.420	85,170	100,200
1900	2.019	40,375	47,500	1.628	65,110	76,600	1.427	85,595	100,700
1800	2.032	40,630	47,800	1.638	65,535	77,100	1.446	86,785	102,100
1700	2.049	40,970	48,200	1.651	66,045	77,700	1.456	87,380	102,800
1600	2.078	41,565	48,900	1.664	66,555	78,300	1.466	87,380	103,500
* 1500	2.108	42,160	49,600	1.677	67,065	78,900	1.485	89,080	104,800
1400	2.172	43,435	51,100	1.730	69,190	81,400	1.507	90,440	106,400
1300	2.202	44,030	51,800	1.753	70,125	82,500	1.527	91,630	107,800
Injection Rate 70 Barrels of Fracturing Fluid Per Minute									
2500	2.125	42,500	50,000	1.726	69,020	81,200	1.479	88,740	104,400
2400	2.159	43,180	50,800	1.749	69,955	82,300	1.499	89,930	105,800
2300	2.176	43,520	51,200	1.757	70,295	82,700	1.520	91,205	107,300
2200	2.193	43,860	51,600	1.766	70,635	83,100	1.530	91,800	108,000
2100	2.223	44,455	52,300	1.774	70,975	83,500	1.540	92,395	108,700
* 2000	2.257	45,135	53,100	1.798	71,910	84,600	1.561	93,670	110,200
1900	2.316	46,325	54,500	1.828	73,100	86,000	1.575	94,520	111,200
1800	2.333	46,665	54,900	1.857	74,290	87,400	1.590	95,370	112,200
1700	2.350	47,005	55,300	1.887	75,480	88,800	1.604	96,220	113,200

*Typical Injection Rate for Berea Sand in Pike County, Kentucky.

the formation. Generally, the average number of perforations is two shots per foot; occasionally three shots per foot are used.

The top 20 feet of the Berea formation is usually a tight siltstone and is not perforated.

The trend in perforating the Berea is to reduce the number of perforations in order to inject water and sand through each perforation. The reduction in number of perforations has cut down the use of "perf balls" and stage treatments.

Cement top and perforating depth control logs are run on all wells to determine the cement tops and to assure proper location of the perforations. The only variance from this procedure is in a homogeneous porosity zone where a single point entry is desired over multiple perforations.

The size, type of treatment, and the pumping horsepower requirements for the fracture treatments depend largely upon the previously perforated zones which were inversely selected from the projected treating pressures and injection rates of fluid and sand (pl. 4, in envelope).

Higher sand concentration rates with the injection rates and treating pressure stated above usually cause the well to sand off before the treatment is completed.

The average amount of material and equipment used in fracturing the Berea sand in Pike County during 1962 was as follows:

1. 250 gallons of 15% M. C. A. acid.
2. 46,000 pounds of 20-40 mesh sand.
3. 26,000 gallons of sand-laden water.
4. 46 barrels/minute fluid injection rate.
5. 1.65 pounds sand/gallon of fluid.
6. Equipment requirements: the number of pumping and sand blending units required to inject fluid and sand from 50 to 70 barrels per minute with sand concentration up to 3 pounds per gallon of fluid.

These fractured wells are swabbed until enough gas flow is obtained for them to clean themselves. They are shut in and blown periodically until both sand and water are cleaned from the production string. Two-inch tubing is usually run as a siphon string before the well is turned into the line.

ECONOMICS

Figure 2 is a typical production-decline curve for a fractured Berea sand well in Pike County. Since the sustained production history is limited to the older wells, this average is based on several open hole completions.

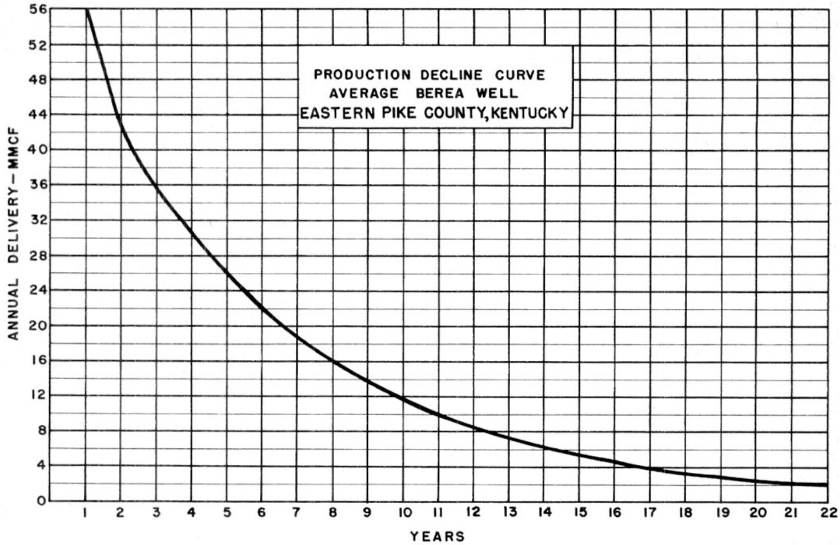

Fig. 2. Production decline curve of average Berea sand well in eastern Pike County, Kentucky.

The cost of a set through, fractured Berea sand well 3700 feet deep in Pike County, Kentucky, is approximately $47,000. This price is assuming the recovery of both 7-inch and 8 5/8-inch casings strings.

Drilling is currently on approximately 200 acre spacing. Reserves are calculated to be 2.30 MMCF per acre at a reservoir pressure of 750 psi.

Pay out time on the average Berea well should be from five to seven years depending on marketing conditions in the area.

CONCLUSION

In conclusion, the writer believe that these new completion practices will extend Berea sand gas production to western Pike County and possibly to other sections of eastern Kentucky. However, this statement should not be construed to mean that all one has to do to obtain commercial Berea production is to drill at random, log, cement pipe, and fracture the most porous zones.

An exploratory program of this nature requires extensive use of geology and reservoir engineering in order to be economical.

Several Berea sand wells have been completed by set through and hydraulic fracturing methods in areas of depleted "Brown Shale" production. In one well in Floyd County, the shale pressure had declined to less than 150 psi., but the shut in pressure on the Berea after fracture was over 400 psi. This pressure may appear to be low until one considers the depth of less than 1500 feet.

The reservoir pressure is adequate for commercial production if fracturing and new completion methods can develop the open flow or deliverability required.

Many wells in eastern Kentucky have been drilled through the Berea sand and the "Brown Shale" has been shot for production. Here lies unknown reserves of gas that may possibly be recovered with a well planned workover program.

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OIL PRODUCTION IN KENTUCKY FOR YEAR 1962

Compiled by Kentucky Geological Survey, Lexington, Kentucky

County	*Barrels*
Allen	116,231
Barren	43,240
Bath	5,355
Breathitt	111,113
Breckinridge	118,349
Boyd	580
Butler	347,435
Casey	34,263
Christian	935,971
Clinton	125,064
Crittenden	163
Cumberland	48,419
Daviess	1,749,337
Edmonson	807
Elliott	64,201
Estill	178,494
Floyd	15,394
Garrard	51
Grayson	61
Green	466,101
Hancock	255,291
Hardin	2,662
Hart	37,337
Henderson	3,492,700
Hopkins	270,585
Jackson	1,193
Johnson	184,591
Knott	15,168
Knox	1,795
Laurel	1,074
Lawrence	408,758
Lee	1,709,775
Leslie	3,944
Letcher	9,663
Lincoln	7,820
Logan	898
McCreary	16,936
McLean	835,979
Magoffin	1,021,787
Martin	19,937
Meade	74
Menifee	517
Metcalfe	190,180
Monroe	109
Morgan	738
Muhlenberg	685,430
Ohio	940,609
Owsley	1,188
Perry	4,668
Pike	44,131
Powell	264,140
Russell	5,429
Simpson	11,086
Taylor	10,817
Todd	7,323
Union	1,555,234
Warren	44,762
Wayne	26,450
Webster	1,283,799
Whitley	29,303
Wolfe	24,869
Total	17,789,378