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Risks and Rewards of Well Drilling in the Devonian Shale

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ABSTRACT

This paper addresses the risks and rewards associated with Devonian shale gas wells in West Virginia, Ohio, and Kentucky. In the development thereof, both geoscience and geostatistical studies were pursued. A geoscience approach was used to identify the plays or groups of counties in each of the three states having similar geology. Within these plays, data from existing wells were acquired to quantify reservoir parameters (pressure, depth, well spacing, and productive interval). Afterwards, a dual-porosity, single-phase simulator was used to forecast expected performance from stimulated wells. Using these curves, reserves were estimated for each play.

A geostatistical approach was used to rank and quantify the risk (probability of production) associated with drilling and producing Devonian shale wells in selected plays. The rewards associated with new well drilling ventures were addressed in the economic parameters of payout time and return on investment. This study should be of interest to Appalachian independents and businesses considering development of shale gas wells. It should reduce considerable uncertainty relative to areas worthy of drilling and, within them, options for stimulation.

INTRODUCTION

The recent downturn in petroleum and natural gas prices has depressed the development of Devonian shale reserves within the Appalachian Basin. The high-risk nature of drilling Devonian shale wells exists because of a lack of operator knowledge on prediction of natural fracture spacing orientation and occurrence, proper well pattern and spacing, and expected reservoir performance from a variety of stimulation technologies.

References and illustrations at end of paper.

The Department of Energy's eastern gas shales project has established the geologic framework of Devonian shale stratigraphy over the entire Appalachian Basin such that operators can high grade areas of greater organic-rich shale from maps.[1] In addition, over 20,000 feet of oriented cores and well logs from 35 wells have been analyzed for geologic reservoir properties such as porosity, permeability, natural fracture spacing, gas content, and mineralogical analysis to permit engineering studies to be made.[2] In this effort, reservoir simulators like "SUGAR" have been developed to predict reservoir performance using the core and well log data. Key features of the SUGAR model include the ability to model matrix and natural fracture fluid flow as well as desorption of gas from a tight shale matrix.

Recent industry surveys on investment analysis indicate that nondiscounted methods like payback period and return on investment are key indicators for decision making.[3]

TECHNICAL APPROACH

In order to understand the impact of extraction technology on the development of Devonian shale gas resources, a systematic geoscience approach was developed to partition the regional extent of Devonian shale gas resources in a three-state area of West Virginia, Ohio, and Kentucky. Key technical issues to be addressed include identification of key geotechnical variables that distinguish one region from another. The approach taken was to assemble horizontal stress trajectory, natural fracture orientation, mechanic fabric trend, and permeability anisotropy data to partition areas expected to have similar shale geology (Figure 1). Within these partitioned areas, expected gas recovery for different stimulation methods were predicted and risk/rewards related to them were calculated to evaluate future drilling ventures in a specific area.

RESULTS/OBSERVATIONS

Technically Recoverable Gas

Technically recoverable gas from the Devonian shales is estimated at 26 Tcf using traditional borehole shooting technology. With advanced stimulation and the development of new shale areas, the potential could reach 83 Tcf. Where a number of geologic studies have been completed, sufficient data exists to further subdivide the setting into partitioned areas or plays (Figure 2). In the accomplishment thereof, computer history matching of simulated to actual production data was the technique employed to establish the reservoir parameters for a particular play. Specifically, long-term gas production data were used for the history match to determine the product of fracture permeability and net productive thickness. Representative wells were identified for those counties where sufficient production data were available to characterize the resource in a statistically meaningful way. In selecting representative wells, the data base was screened to identify wells (1) that were individually metered; (2) that had production from shale members distinguishable from other nonshale producing horizons; (3) that included high, average, and low producers; and, (4) had at least 5 years of production data.

Using the reservoir properties known for the representative counties, the model was employed to determine fracture permeability and the "net productive shale thickness" that matched the initial gas flow rate as well as matched long-term gas production. Technically recoverable gas was then calculated for each area as shown in Tables 1, 2, and 3.

Kentucky

Technically recoverable gas from the Devonian shales of Kentucky is estimated at 9.4 Tcf using traditional borehole shooting in the currently drilled areas of the state. With advanced stimulation (600-foot fractures) and the development of new shale areas, the potential could reach 23.2 Tcf.[4]

Part of the traditional producing area of the Big Sandy Field lies in eastern Kentucky and has produced natural gas from Devonian shale since the 1880's. Thus, remaining drillable area in this region has declined over time. For instance, in Martin and Floyd Counties, due to the extensive development in the last century (over 1,200 Devonian shale wells in this two-county area alone) only 319 square miles of a potential 630 square miles is now considered as undeveloped. The gas in-place for the entire setting (traditional producing area) is estimated to be 19.5 Tcf. As expected in this area, comparatively high permeability, thick net pay, limited anisotropy, and a close fracture spacing of 5-feet lead to a good gas recovery per well (962 MMcf in 40 years with borehole shooting), although the recovery efficiency is moderate, at 43 percent of the gas in-place. Moving northward from the Big Sandy Field area towards Lawrence and Johnson Counties and westward to Leslie and Perry Counties, per well production estimates range from 305 MMcf to 592 MMcf depending on stimulation. Recovery efficiencies range from 47 percent recovery of the gas in-place with borehole shooting to 79 percent recovery with advanced technology.

West Virginia

The total recoverable Devonian shale gas from West Virginia is estimated to range from 11.1 to 44.5 Tcf, depending on the completion and stimulation technology employed.[5] Of this, 11 to 18 Tcf are recoverable from the better defined western portion of the state where the gas production is from the Huron and Rhinestreet members. In the traditional producing area of Wayne, Lincoln, Logan, and Mingo Counties, favorable reservoir properties such as high permeability, thick net pay, limited anisotropy, and close fracture spacing (5-10 feet) lead to high gas recoveries per well: 446 MMcf in 40 years with borehole shooting. Large vertical fracturing adds little to ultimate recovery.

As drilling progresses northward, the estimates of recovery decrease towards the northern edge of the producing area comprised of Pleasants, Ritchie, and Wood Counties. Higher rock pressures, moderate net thicknesses and low natural fracture permeability combine to give per well recoveries of 218 MMcf (borehole shooting) and 355 MMcf (large vertical fracturing).

Ohio

The analysis shows that the gas flow rates and ultimate recovery per well vary widely in Ohio, from relatively high gas production in the south to low production rates in the shallow, northern area along Lake Erie. The total recoverable gas in the state is estimated to range from 6.2 Tcf with borehole shooting to 15.2 Tcf with advanced stimulation (massive hydraulic fracturing).[6]

In the southern portion of Ohio, in Lawrence and Gallia Counties, high gas recovery is due to favorable reservoir properties, such as high pressure, good net thickness, and close fracture spacing (5-10 feet). Per well recoveries for borehole shooting are 386 MMcf with traditional technology and increase to 1,080 MMcf with large vertical fracturing. As drilling progresses northward, despite the high adsorbed gas content, the production estimates decline due to low rock pressures. Estimates per well in the north central countie , Wayne and Stark Counties, range from 79 MMcf (borehole shooting) to 320 MMcf (large vertical fracturing). Gas production in northern Ohio is limited by low rock pressures in the shallow shales despite good gas contents and shale thicknesses.

Probability of Production -- The Risk

The probability of success associated with new shale gas well ventures within the partition areas of the states Kentucky, West Virginia, and Ohio was derived from a statistical analysis of available production data and is the sole indicator of risk used in this study. In the development thereof, cumulative frequency distribution plots were made to show how one state compares with another. These are shown in Figure 3. The number of data points used to make the plots for Kentucky, West Virginia, and Ohio were 655, 304, and 82, respectively. These plots enable one to readily make relative comparisons and to provide a general picture of the region based on sparse but actual production data. The geology and related reservoir characteristics are not explicitly taken into account.

If the criteria for a successful well is thought to be indicative of an open flow potential greater than 300 MCFD following stimulation, then the probability of success in Kentucky is .77, in West Virginia it is .51, and in Ohio it is .10.[7] Open flow potentials exceeding 300 MCFD have typically produced 100 million cubic feet (MMCF) in 3 years and have a cumulative production of 600 MMCF over 40 years. Production probabilities for the partition areas with the three states were obtained from data populations within them. Where data was lacking for a partition, the probability value for the area adjacent to it was used.

Economics -- The Rewards

A Devonian Shale Gas Economics Model (DGEM) has been developed for the Morgantown Energy Technology Center (METC). Its purpose is to allow for the economic appraisal of gas production from Devonian shales in a variety of geologic setting, and using a variety of stimulation technologies. The model is "user-friendly" such that, through its interactive application, the user can define the values desired for the important parameters affecting the economic appraisal of Devonian shale gas production.

The user can perform evaluations of Devonian shale projects in any of three ways:

- Define a required return on investment and determine the minimum required gas selling price.
- Define a gas selling price and determine the required return on capital investment.
- Define a gas price and required return on investment and calculate the cash flow resulting from a project.

Analysis using DGEM can be performed on a single-well or a multi-well pattern for any defined project life for a well or field. Several different stimulation methods (borehole shooting, radial stimulation, or hydraulic fracturing) can be modeled or no stimulation can be assumed. Values for engineering costs are determined based on location, reservoir depth, gas production rate, and stimulation methods. The user can then use these predetermined costs or can define their own.

Important parameters affecting this economic analysis are reservoir depth, production rate, net productive thickness, well spacing, dry hole success rate, and the stimulation type used. For each partitioned area, a representative reservoir depth, net production thickness, and reservoir performance data (flow rate versus time) was used as input. The DGEM model was run using a $2.00/Mcf gas price to determine cash flow parameters for each of the partitioned areas. Tables 4, 5, and 6 show the risk and reward of drilling ventures in each partitioned area of Figure 1.

CONCLUSIONS

Kentucky

Area I is represented by Floyd County and has been one of the prime shale producing areas of Kentucky. Provided a suitable well spacing and suitable reservoir pressure could be found in this heavily drilled area, well bore shooting could be an attractive investment at a 26 percent return on investment for a $2/Mcf gas price. The use of conventional size 150-foot hydraulic fractures in three areas represented by Pike, Perry, and Lawrence Counties could result in attractive returns on investment ranging from 13 to 32 percent with payout times from 3 to 6 years.

West Virginia

Devonian shale gas can be economically produced at a $\geq$ 15 percent return on investment in portions of three partitioned areas represented by Logan, Lincoln, and Jackson Counties, West Virginia. As a minimum, conventional hydraulic fracture treatments designed to achieve 150-foot fracture half-lengths are required. Payout times are calculated to be from 3 to 4 years. Other areas represented by Kanawha, Ritchie, and Fayette produced a return on investment from 4.8 to 7.5 percent only after using 600-foot hydraulic fractures. Certainly under the present wellhead prices of natural gas, these areas will not be developed.

Ohio

The economics of drilling shale wells in Ohio appear attractive in Area 1 represented by Lawrence County. In this area, conventional hydraulic fracturing could potentially yield a 20 percent return on investment. Marginal rewards are identified for Area 2 (Licking County) but only when massive fracturing technology is used to create 600-foot hydraulic fractures. For all other areas in Ohio, the economic attractiveness is drastically reduced based on current market wellhead prices for natural gas.

ACKNOWLEDGEMENTS

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TABLE 1—TECHNICALLY RECOVERABLE GAS FROM DEVONIAN SHALES OF KENTUCKY

STATE OF KENTUCKY			TECHNICALLY RECOVERABLE GAS (TCF) IN 40 YEARS			
PARTITIONED AREA	TOTAL DRILLABLE AREA (SQ. MI)	TARGET GAS IN PLACE (TCF)	BOREHOLE SHOOTING	RADIAL STIMULATION $r'_w = 30'$	SMALL RADIAL STIMULATION $X_f = 150'$	LARGE VERTICAL FRACTURE $X_f = 600'$
1. GEOLOGIC SETTING I						
AREA I	319	5.4	2.5	3.2	3.8	4.4
AREA II	474	2.8	1.7	2.0	2.3	2.4
AREA III	919	8.1	3.7	4.8	5.5	6.3
AREA IV	615	3.2	1.5	2.0	2.4	2.9
TOTAL	2,327	19.5	9.4	12.0	14.0	16.0

TABLE 2—TECHNICALLY RECOVERABLE GAS FROM DEVONIAN SHALES OF WEST VIRGINIA

STATE OF WEST VIRGINIA			TECHNICALLY RECOVERABLE GAS (TCF) IN 40 YEARS			
PARTITIONED AREA	TOTAL DRILLABLE AREA (SQ. MI)	TARGET GAS IN PLACE (TCF)	BOREHOLE SHOOTING	RADIAL STIMULATION $r'_w = 30'$	SMALL RADIAL STIMULATION $X_f = 150'$	LARGE VERTICAL FRACTURE $X_f = 600'$
1. GEOLOGICAL SETTING I						
AREA I	189	0.7	0.5	0.5	0.5	0.5
AREA II	688	5.1	2.4	3.0	3.5	3.9
AREA III	1,480	6.9	2.8	4.2	4.7	5.4
AREA IV	623	2.2	1.6	1.7	1.8	1.8
AREA V	1,379	7.2	2.4	3.2	3.6	4.4
AREA VI	809	3.2	1.4	1.8	2.0	2.3
TOTAL	5,168	25.3	11.1	14.4	16.1	18.3

TABLE 3—TECHNICALLY RECOVERABLE GAS FROM DEVONIAN SHALES OF OHIO

STATE OF OHIO			TECHNICALLY RECOVERABLE GAS (TCF) IN 40 YEARS			
PARTITIONED AREA	TOTAL DRILLABLE AREA (SQ. MI)	TARGET GAS IN PLACE (TCF)	BOREHOLE SHOOTING	SMALL RADIAL STIMULATION $r'_w = 30'$	SMALL VERTICAL FRACTURE $X_f = 150'$	LARGE VERTICAL FRACTURE $X_f = 600'$
1. GEOLOGIC SETTING I						
AREA I	543	4.1	0.84	1.16	1.58	2.35
AREA II	3,577	12.4	2.95	4.06	4.67	6.21
AREA III	2,869	4.4	1.46	1.98	2.33	3.04
AREA IV	2,641	24.8	0.84	1.35	1.78	3.38
AREA V	313	0.4	0.05	0.06	0.06	N.A.
AREA VI	1,035	3.3	0.04	0.07	0.09	0.20
TOTAL	10,978	49.4	6.18	8.68	10.52	15.18

TABLE 4—RISKS/REWARDS FOR KENTUCKY (gas price @ $2.00/Mcf)

			RISKS			REWARDS	
AREA	COUNTIES	STIMULATION METHOD	PROBABILITY OF PRODUCTION*	TOTAL INVESTMENT (THOUSANDS)	40 YR PRODUCTION (MMCF)	PAYOUT TIME (YRS)	RETURN ON INVESTMENT (PERCENT)
I	FLOYD	BOREHOLE SHOOTING	79	157	948	4 54	25 67
		30 RADIAL STIMULATION		184	1240	3 17	40 06
		150 HYDRAULIC FRACTURE		197	1471	1 24	64 69
		600 HYDRAULIC FRACTURE		235	1703	1 07	100 00
II	PIKE	BOREHOLE SHOOTING	76	189	446	8 85	9 29
		30 RADIAL STIMULATION		202	534	5 63	15 84
		150 HYDRAULIC FRACTURE		210	592	2 77	25 49
		600 HYDRAULIC FRACTURE		229	634	1 96	56 27
III	PERRY	BOREHOLE SHOOTING	79	165	492	8 70	10 60
		30 RADIAL STIMULATION		179	652	4 88	20 65
		150 HYDRAULIC FRACTURE		188	740	3 29	32 72
		600 HYDRAULIC FRACTURE		207	852	1 61	78 13
IV	LAWRENCE	BOREHOLE SHOOTING	85	149	30[illegible]	16 20	4 17
		30 RADIAL STIMULATION		162	406	9 43	8 91
		150 HYDRAULIC FRACTURE		171	478	6 45	13 94
		600 HYDRAULIC FRACTURE		190	590	4 02	32 68

*IOF 300 MCFD

TABLE 5—RISKS/REWARDS FOR WEST VIRGINIA (gas price @ $2.00/Mcf)

			RISKS			REWARDS	
AREA	COUNTIES	STIMULATION METHOD	PROBABILITY OF PRODUCTION*	TOTAL INVESTMENT (THOUSANDS)	40 YR PRODUCTION (MMCF)	PAYOUT TIME (YRS)	RETURN ON INVESTMENT (PERCENT)
I	LINCOLN	BOREHOLE SHOOTING	67	169	307	7 52	8 68
		30 RADIAL STIMULATION		180	321	4 94	14 30
		150 HYDRAULIC FRACTURE		188	323	3 63	20 60
		600 HYDRAULIC FRACTURE		204	324	2 18	35 73
II	LOGAN	BOREHOLE SHOOTING	53	167	440	9 53	9 12
		30 RADIAL STIMULATION		185	549	6 25	14 88
		150 HYDRAULIC FRACTURE		195	626	4 15	23 97
		600 HYDRAULIC FRACTURE		222	702	2 10	55 00
III	FAYETTE	BOREHOLE SHOOTING	50	313	232	**	0 00
		30 RADIAL STIMULATION		327	349	36 96	0 09
		150 HYDRAULIC FRACTURE		336	394	19 79	1 47
		600 HYDRAULIC FRACTURE		356	459	9 99	4 87
IV	JACKSON	BOREHOLE SHOOTING	42	180	313	10 07	5 95
		30 RADIAL STIMULATION		190	344	6 47	10 48
		150 HYDRAULIC FRACTURE		198	357	4 78	14 90
		600 HYDRAULIC FRACTURE		213	366	2 84	27 00
V	KANAWHA	BOREHOLE SHOOTING	53	214	213	**	0 00
		30 RADIAL STIMULATION		229	285	30 69	0 53
		150 HYDRAULIC FRACTURE		238	337	29 05	2 45
		600 HYDRAULIC FRACTURE		260	413	8 44	7 46
VI	RITCHIE	BOREHOLE SHOOTING	42	195	216	**	0 00
		30 RADIAL STIMULATION		207	279	21 13	1 22
		150' HYDRAULIC FRACTURE		216	307	16 65	2 62
		600' HYDRAULIC FRACTURE		233	354	8 15	6 93

*IOF - 300 MCFD **PAYOUT TIME > PRODUCTION LIFE

TABLE 6—RISKS/REWARDS FOR OHIO (gas price @ $2.00/Mcf)

			RISKS			REWARDS	
AREA	COUNTIES	STIMULATION METHOD	PROBABILITY OF PRODUCTION*	TOTAL INVESTMENT (THOUSANDS)	40 YR PRODUCTION (MMCF)	PAYOUT TIME (YRS)	RETURN ON INVESTMENT (PERCENT)
I	LAWRENCE	BOREHOLE SHOOTING	19	126	386	12 64	7 35
		30 RADIAL STIMULATION		141	527	8 61	11 68
		150 HYDRAULIC FRACTURE		150	719	5 22	20 39
		600 HYDRAULIC FRACTURE		172	1069	3 63	49 24
II	LICKING	BOREHOLE SHOOTING	0	102	202	25 02	1 75
		30 RADIAL STIMULATION		112	279	14 21	5 42
		150 HYDRAULIC FRACTURE		120	322	11 53	7 24
		600 HYDRAULIC FRACTURE		136	420	7 20	12 83
III	GUERNSEY	BOREHOLE SHOOTING	< 01	170	125	**	0 00
		30 RADIAL STIMULATION		183	170	**	0 00
		150 HYDRAULIC FRACTURE		191	200	**	0 00
		600 HYDRAULIC FRACTURE		210	264	23 59	0 39
IV	WAYNE	BOREHOLE SHOOTING	< 01	105	77	**	0 00
		30 RADIAL STIMULATION		117	125	**	0 00
		150 HYDRAULIC FRACTURE		125	165	**	0 00
		600 HYDRAULIC FRACTURE		144	314	16 90	4 42
V	HURON	BOREHOLE SHOOTING	< 01	78	38	**	0 00
		30 RADIAL STIMULATION		85	46	**	0 00
		150 HYDRAULIC FRACTURE		92	49	**	0 00
		600 HYDRAULIC FRACTURE		103	60	**	0 00
VI	TRUMBULL	BOREHOLE SHOOTING	< 01	117	10	**	0 00
		30 RADIAL STIMULATION		128	17	**	0 00
		150 HYDRAULIC FRACTURE		136	22	**	0 00
		600 HYDRAULIC FRACTURE		153	46	**	0 00

*IOF [illegible]00 MCFD **PAYOUT TIME > PRODUCTION LIFE

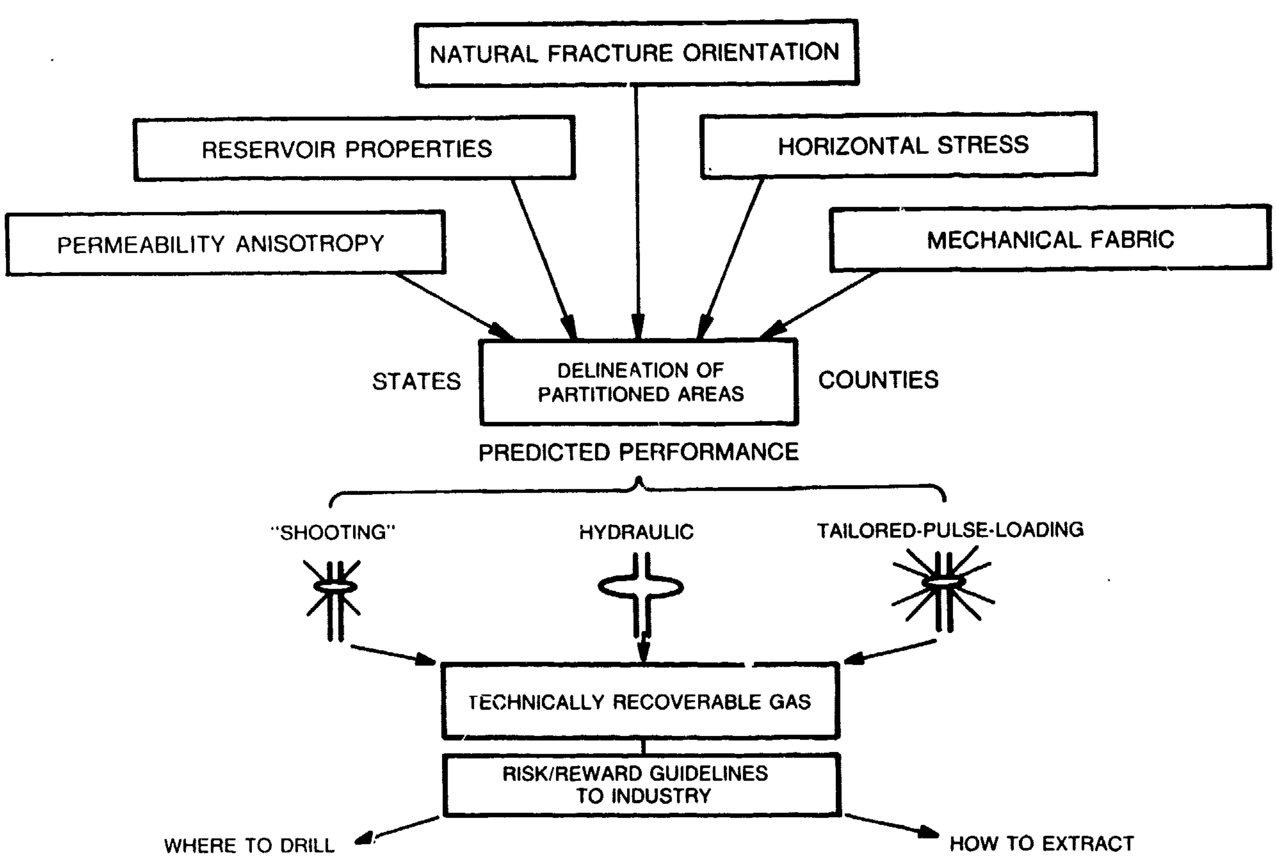

Fig. 1—Technical approach to quantifying parameters to estimate recoverable gas.

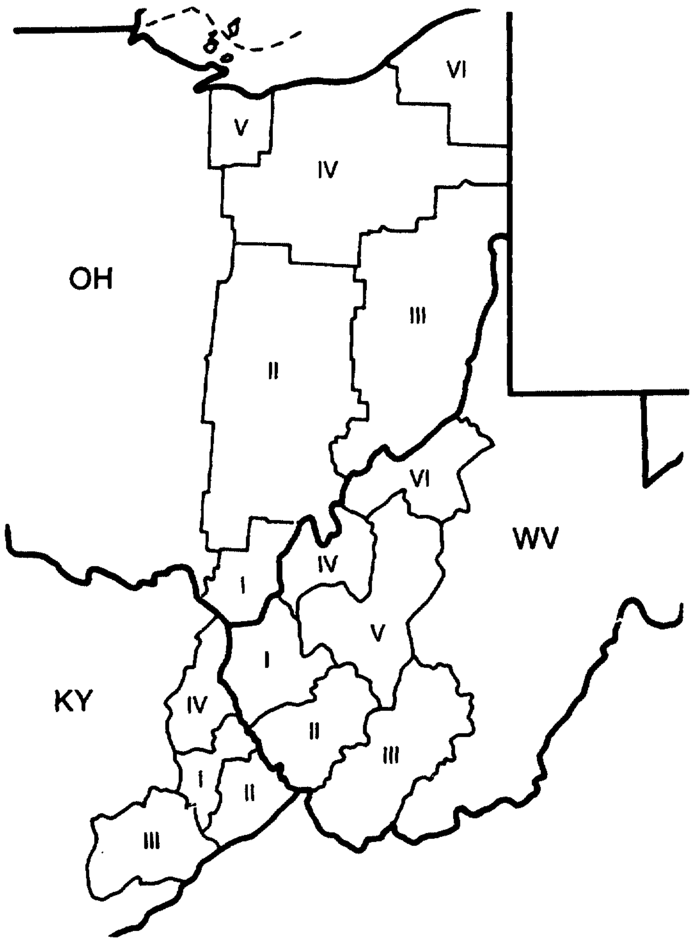

Fig. 2—Partitioned areas of the Appalachian Basin.

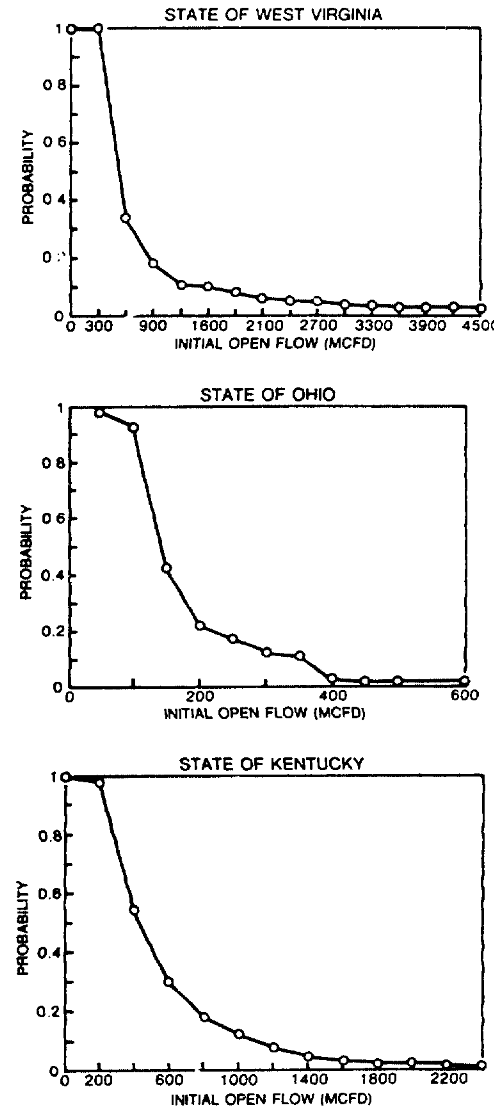

Fig. 3—Probability of production potential.

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