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NATURAL GAS FROM UNCONVENTIONAL GEOLOGIC SOURCES

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CHAPTER 7

DEVONIAN SHALE DEVELOPMENT IN EASTERN KENTUCKY

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INTRODUCTION

Exploratory drilling in eastern Kentucky has persisted for over 150 years. The area has undergone the classic Appalachian evolution--the initial search for salt brine, boom of the 1860s when oil gained a market for lighting and heating, and the realization of the importance of natural gas in the early 1920s.

This paper deals with data from what is historically termed the "Big Sandy Field" located geographically in Lawrence, Johnson, Martin, Magoffin, Floyd, Pike, Letcher, Knott, Perry, Leslie, and Breathitt Counties (see Figure 7.1). Early development in Floyd County in the drainage basin of the Big Sandy River gave the name to the field; a more appropriate term today is the Eastern Kentucky Field, since drilling has expanded development into the drainage areas of both the Kentucky and Licking Rivers. The field lies within the Appalachian Plateau, between the Cincinnati Arch to the west and the Appalachian Front to the east.

GEOLOGIC SETTING

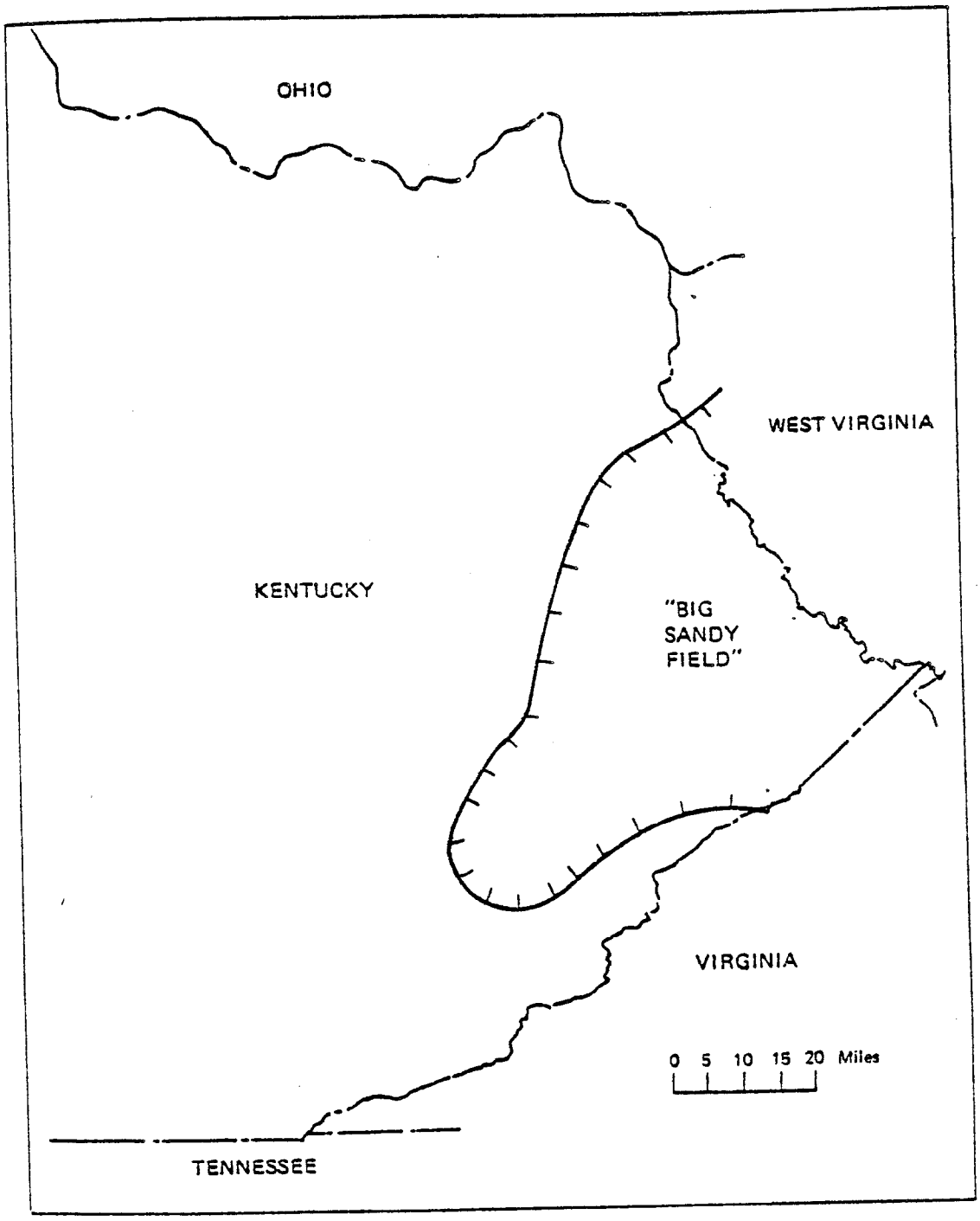
The Eastern Kentucky Field is the southernmost major component of Post-Ordovician oil and gas fields of the Appalachian region which extends southward from the State of New York.

The Upper Devonian shale, locally termed the Brown Shale, is the most important producer in the Eastern Kentucky Field. This productive unit lies between the Lower Mississippian Berea Sand and the "Corniferous" of Kentucky, or Onondaga of Middle Devonian age.

Post-Ordovician strata in the field strike generally northeast and dip to the southeast. The Devonian Shales have a monoclinal dip to the southeast of 30 to 50 feet per mile, and in producing areas have a thickness of 200 to 900 feet. The Devonian Shales thin to the west as the eastern flank of the Cincinnati Arch is approached.

FIGURE 7.1

Big Sandy Field, Eastern Kentucky



These shales are a component of the Devonian Catskill delta system and are a facies of the Middle and Upper Devonian formations of West Virginia, Pennsylvania, and New York. The black shales of the Eastern Kentucky Field represent the terminal cycle of the deltaic deposition. The productive sandstones of Pennsylvania and West Virginia, such as the Venango, Fourth-Fifth Sands, Speechley, Bradford, Gantz, Gordon, Benson, and Riley are not present.

DEVELOPMENT

As of December 31, 1974, approximately 8,312 wells had been drilled within the Big Sandy or Eastern Kentucky Field. Wells associated with oil pool development are excluded. A total of 1,146 dry holes (14 percent) have been non-productive. A total of 4,616 wells have been classified as Devonian Shale gas producers which represent 56 percent of the total completions. The remaining 2,550 completions were primarily in Pennsylvanian and Mississippian strata.

It is estimated that at least 85 percent of the annual natural gas production from the Commonwealth of Kentucky is from the Eastern Kentucky Field. The American Gas Association (1975) lists Kentucky's preliminary net annual production for 1974 as 59,781 MMcf. The cumulative production through the year 1974 for the entire state is listed as 3,138,369 MMcf. The same source estimates the ultimate recovery to be 3,864,974 MMcf. Based upon the production records of 43 percent of the wells drilled in Eastern Kentucky Field, the estimates shown in Table 7.1 were made for gas produced in Kentucky.

TABLE 7.1

Gas Production in Kentucky

Cumulative Production to December 31, 1974	3,138,369 MMcf
Cumulative for Eastern Kentucky Field	2,824,532 MMcf[1]
Cumulative in Eastern Kentucky Field--	
Devonian Shale	1,689,456 MMcf[2]
Cumulative per well	366 MMcf[3]

1 85 percent of State total
2 60 percent estimated to be from Devonian Shale
3 4,616 Shale producers

The 4,616 wells classifed as shale producers had an average open flow of 331 Mcf. Based upon production history from 53 percent of the wells, estimates were made of gas reserves in Kentucky as shown in Table 7.2.

TABLE 7.2

Gas Reserves in Kentucky

Estimated Ultimate Recovery Per Well	430	MMcf
Estimated Total Ultimate Recovery	1,984,880	MMcf
Cumulative Production to December 31, 1974	1,689,456	MMcf
Estimated Remaining Reserves	295,424	MMcf
Estimated Remaining Reserves Per Well	64	MMcf[1]
Estimated Remaining Reserves Per Well (active)	78	MMcf[2]

1 4,616 Shale Producers
2 3,785 Shale Producers (estimated that 18 percent of original wells have been abandoned).

STIMULATION PRACTICES

The Devonian Shales have been routinely stimulated for at least 45 years by "shooting", i.e. blasting the entire section from top to bottom with explosives. Only 5 percent of the shale completions have had natural flows in commercial quantities. It was discovered that small initial open flows and shows of gas that were not measurable could be stimulated to become commercial producers by shooting. Approximately 40 percent of the wells in the field had no measurable initial flow before stimulation by explosion. The dry hole experience after shooting is a low 11 percent. After much testing and innovation, the practice of shooting evolved to the standard process of detonating 10 pounds of 80 percent gelatinated nitroglycerin per foot of shale section. Thus, a shale section consisting of 500 feet would be shot with approximately 5,000 pounds of explosives. The process of bridging or tamping the hole to contain the shot has not been extensively practiced due to the difficulty of cleaning out the well with cable tool equipment after shooting.

During 1965, Kentucky-West Virginia Gas Company decided to attempt experimental hydraulic fracturing of the shale section. Plans were to case through, perforate, and inject relatively high volumes of fluid and sand. The first well was treated in June 1965, and to date 106 shale wells have been fractured. After many cementing difficulties and experimenting with sand concentrations, sand size, carring agents, injection rates, additives, etc., the standard treating procedure has evolved to the following:

1. Log and evaluate
2. Set through with 4-1/2 inch casing
3. Cement evaluation log
4. Perforate under mud acid
5. Fracture (Dowell Water Frac 20)

Average Injection Rate - 48 barrels per minute
Average Treating Pressure - 1400 psig
Maximum Sand Rate - 2 lbs per gal.
Sand size and amount:
25,000# 20/40 Mesh
25,000# 10/20 Mesh

Perforations - Average 18 shots, 0.41" size
Treatment Interval - Average 320 feet
Sand Laden Fluid - 1,000 bbl
Single Stage Treatment - Inject perforation ball sealers during treatment to break out all zones

When small amounts of oil from formations above the shale are allowed to drain down the borehole into the shale section, the shale has a tendency to sluff, absorbing the oil and forming a gummy residue that requires remedial "work-over" in gas wells, i.e., setting up a drill rig to clean and re-dress the walls of the gas well. The thought prevailed that fracturing with water would produce the same results, and that the injected water would be largely unrecoverable. Some reasoned that the shale was too unstable to support the sand propping agent, the fractures would heal after the hydraulic pressure had dissipated, and the induced fractures would close.

These thoughts were soon dispelled by actual experience. During the initial stages of the fracturing program, great care was taken to accurately measure fluid recovery after treatment. It was found that up to 80 percent of the injected fluid was recovered within 48 to 60 hours after the hole was cleaned out. The shale was found to be stable enough to sustain induced fractures with the sand propping material.

PRODUCTION FROM FRACTURED SHALE

It was discovered early that open flows in fractured shale were comparable to the flows in conventionally shot shale wells. Naturally, a manifold increase was expected from the fractured shale wells, as compared to the shot wells. Since open flow results were similar from fracturing and shooting, the next step was to put the fractured shale wells on line and evaluate their production characteristics.

For the comparison, a large number of shot well deliverability records were available. The fractured shale wells were categorized by open flow range to make valid comparisons with shot wells with similar open flows. Table 7.3 illustrates that some improvement in open flow has been achieved through fracturing.

In shot shale wells, 54 percent of the total completions have fallen within the Dry Hole and 0-100 Mcf range, while only 43 percent of the total frac shale wells are within

TABLE 7.3

Comparative Completions by Open Flow Ranges,
Hazard Area Shale Wells (Dec. 31, 1974)

O.F Range Mcf/day	Shot Shale Wells No.	% of Total	Frac Shale Wells No.	% of Total
Dry Holes	34	17)	15	16)
0-100	73	37	25	27)
101-200	65	33	34	36
201-300	17	9	12	13
301-1,000	7	4	8	8
Total	196	100%	94	100%

these ranges. A general improvement is recognized in the other ranges also.

The most critical consideration is the actual delivery performance of fractured shale wells as compared with shot shale wells. Table 7.4 and Figures 7.2, 7.3, 7.4, and 7.5 show that fractured shale wells out-perform the shot shale wells in all open flow ranges with respect to actual gas delivery.

An interesting set of figures, Table 7.5, results from a comparison of the years required for a fractured shale well to produce the calculated gas reserve of a shot shale well of comparable open flow.

TABLE 7.4

Comparison of Annual Gas Deliveries Between Fractured Shale Wells and Shot Shale Wells (Dec. 31, 1974)

	Mcf -Year				
	1	2	3	4	5
		0-100 Mcf Range			
Frac	11,443	11,000	9,160	9,575	
Shot	6,921	5,124	5,551	5,186	
Frac Increase:					
Mcf	4,522	5,876	3,609	4,389	
Percentage	65%	115%	65%	85%	
		101-200 Mcf Range			
Frac	16,647	17,464	18,687	16,000	16,200
Shot	13,727	11,270	10,684	9,139	9,683
Frac Increase:					
Mcf	2,920	6,194	8,003	6,861	6,517
Percentage	21%	55%	75%	75%	67%
		201-300 Mcf Range			
Frac	28,343	24,733	20,625	19,625	19,033
Shot	24,681	22,327	17,536	15,500	14,755
Frac Increase:					
Mcf	3,662	2,406	3,089	4,125	4,278
Percentage	15%	11%	18%	27%	29%
		301-1,000 Mcf Range			
Frac	40,333	38,300	35,200	28,700	30,850
Shot	43,562	35,200	27,350	20,980	-
Frac Increase:					
Mcf	(3,229)	3,100	7,850	7,720	
Percentage	(7%)	9%	29%	37%	

TABLE 7.5

Years Required to Produce Calculated Gas Reserves

Open Flow Range	Years to Produce Assigned Reserves	
	Frac well	Shot well
0-100 Mcf	16	32
101-200 Mcf	16	30
201-300 Mcf	23	28

FIGURE 7.2

Open Flow Range: 0-100 Mcf

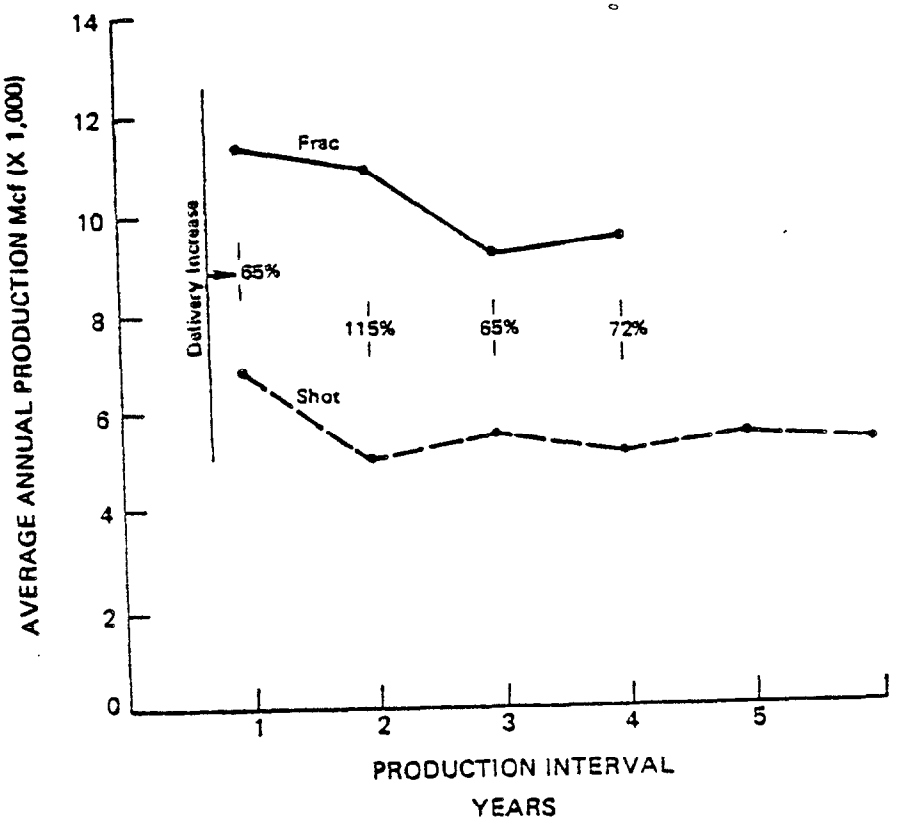


FIGURE 7.3

Open Flow Range: 101-200 Mcf

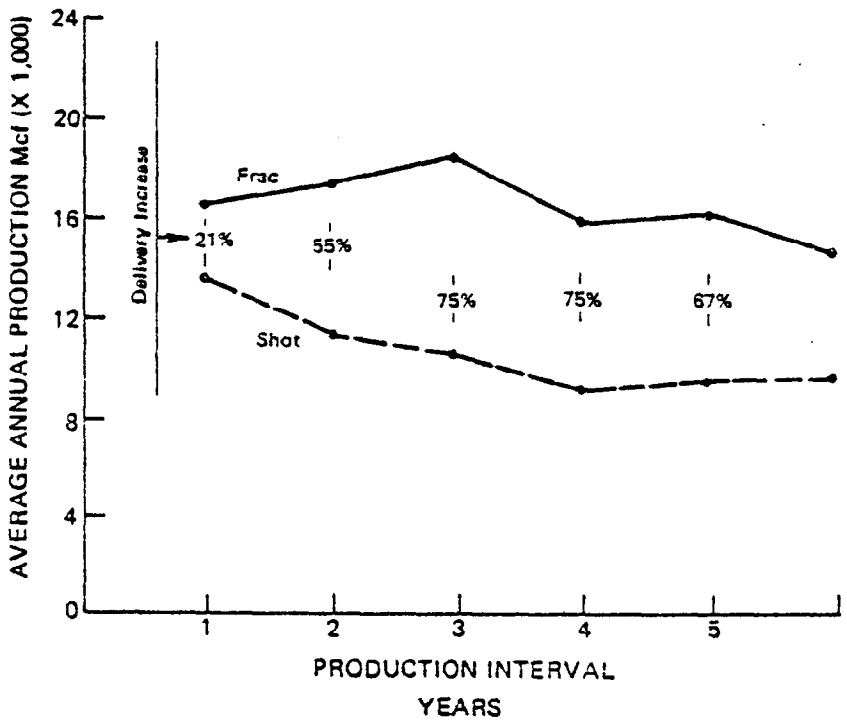


FIGURE 7.4

Open Flow Range: 201-300 Mcf

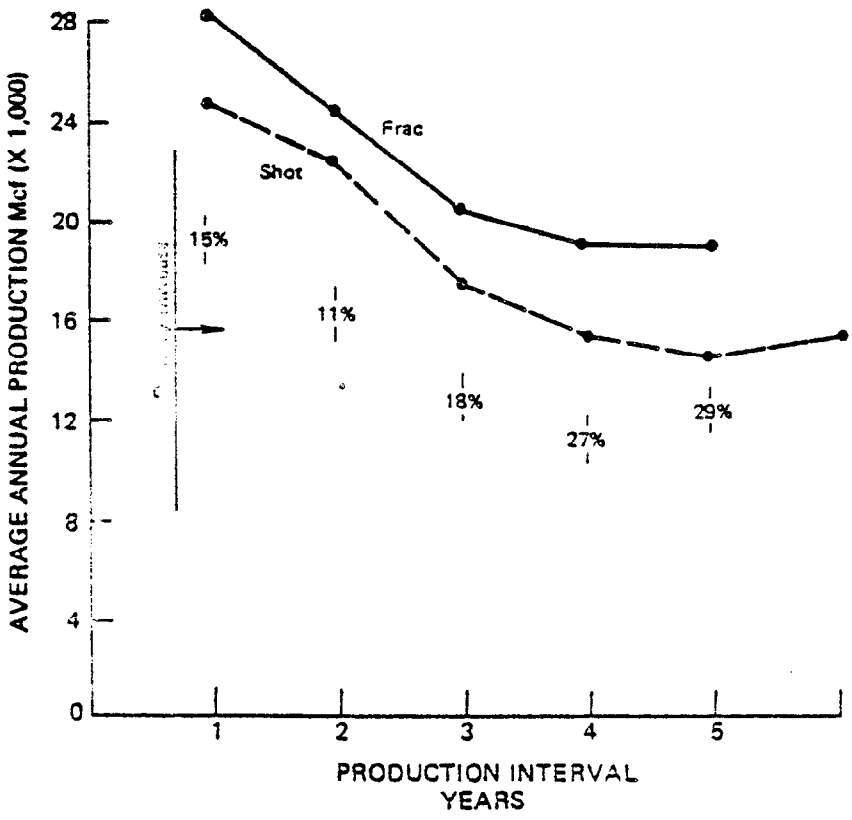
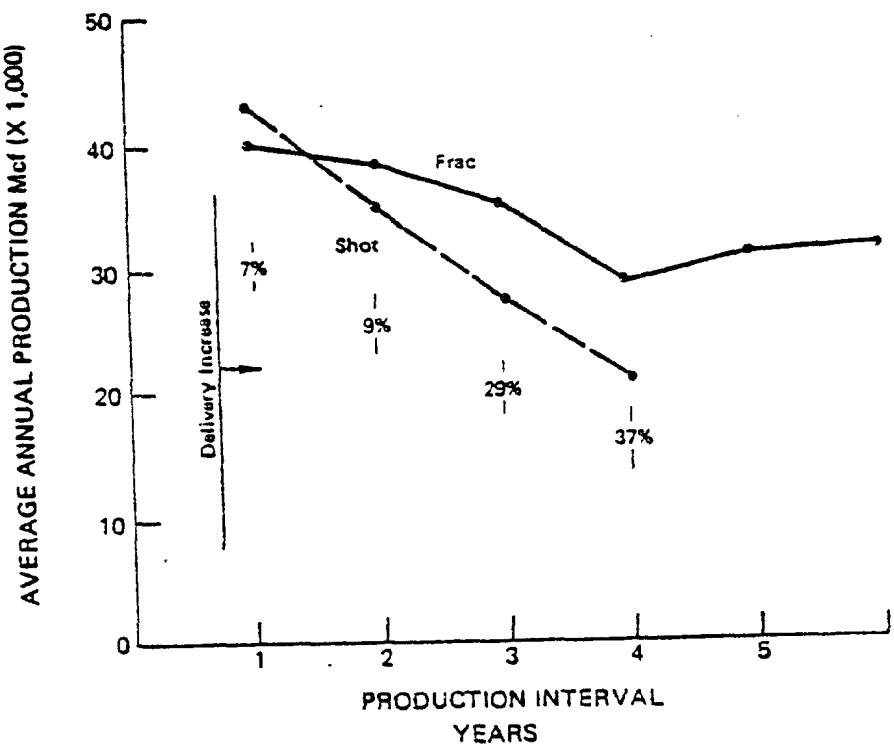


FIGURE 7.5

Open Flow Range: 301-1,000 Mcf



CONCLUSIONS

1. The Devonian Brown Shale of eastern Kentucky is a relatively small volume producer in individual wells; however, the productive life far exceeds any other producing formation in the area.

2. Production data conclusively proves that hydraulic fracturing measurably improves delivery performance.

3. Devonian Shale gas is a rich resource with BTU values up to 1350. Many areas underlain by these shales of substantial thickness in eastern Kentucky are presently considered marginal or non-productive.

4. Any attempts to maximize Devonian Shale production must fall within a feasible economic range under a market structure that will allow exploration and development within the capacity of the operators in the field.

REFERENCE

American Gas Association (1975) Reserve of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada, and United States Productive Capacity as of December 31, 1974. Published jointly by American Gas Association, American Petroleum Institute and Canadian Petroleum Association.