UGR File #62
FE-2281-1, Chapter 6, pp. 86-99
1976
FE-2271-1
Distribution Category UC-92

Natural Gas From Unconventional Geologic Sources

Board on Mineral Resources
Commission on Natural Resources

1976

Contract E(49-18)-2271

NATIONAL ACADEMY OF SCIENCES
Washington, D. C.

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CHAPTER 6

ENERGY FROM SHALE--A LITTLE USED NATURAL RESOURCE

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ABSTRACT

Within the States of Kentucky, Ohio, Virginia, and West Virginia, a total of 9,615 productive gas wells have been drilled in the Devonian Shale in an area of 4,076 square miles. If only 4,076 square miles of the 250,000 square miles of potential producing area between the Appalachian and Rocky Mountains is presently exploited, then only 1.6 percent is being used for gas production at this time. Furthermore, the average shale well recovers only 3 to 8 percent of the calculated gas in place. The ultimate recoverable gas reserves from the 9,615 productive wells is three Tcf.

The majority of the energy contained in the Devonian Shale is not being used; therefore, a list of suggested investigations which may result in improved or new methods to recover more of the energy is included.

Probably 10 to 25 percent of the gas production now being considered as Devonian Shale gas is actually being produced from Mississippian limestones and sandstones.

A possible method to quickly evaluate new stimulation methods is outlined.

ENERGY FROM SHALE--A LITTLE USED NATURAL RESOURCE

This paper deals primarily with the Devonian Shale in the Appalachian Basin, but the remarks are applicable to the Devonian Shale of other areas such as the Michigan and Illinois Basins, and also to organic shales of all ages throughout the United States and the world.

Figure 6.1 shows the approximate extent of Upper Devonian and Lower Mississippian rocks in the central and eastern United States that contain beds of black marine shale. Duncan and Swanson (USGS 1965) state that these shales "are distributed in units ranging in thickness from a few feet to about 800 feet, contain organic matter ranging from 5 to 25 percent of the shale, and yield as much as 7 million BTU per ton of shale by direct combustion". If you

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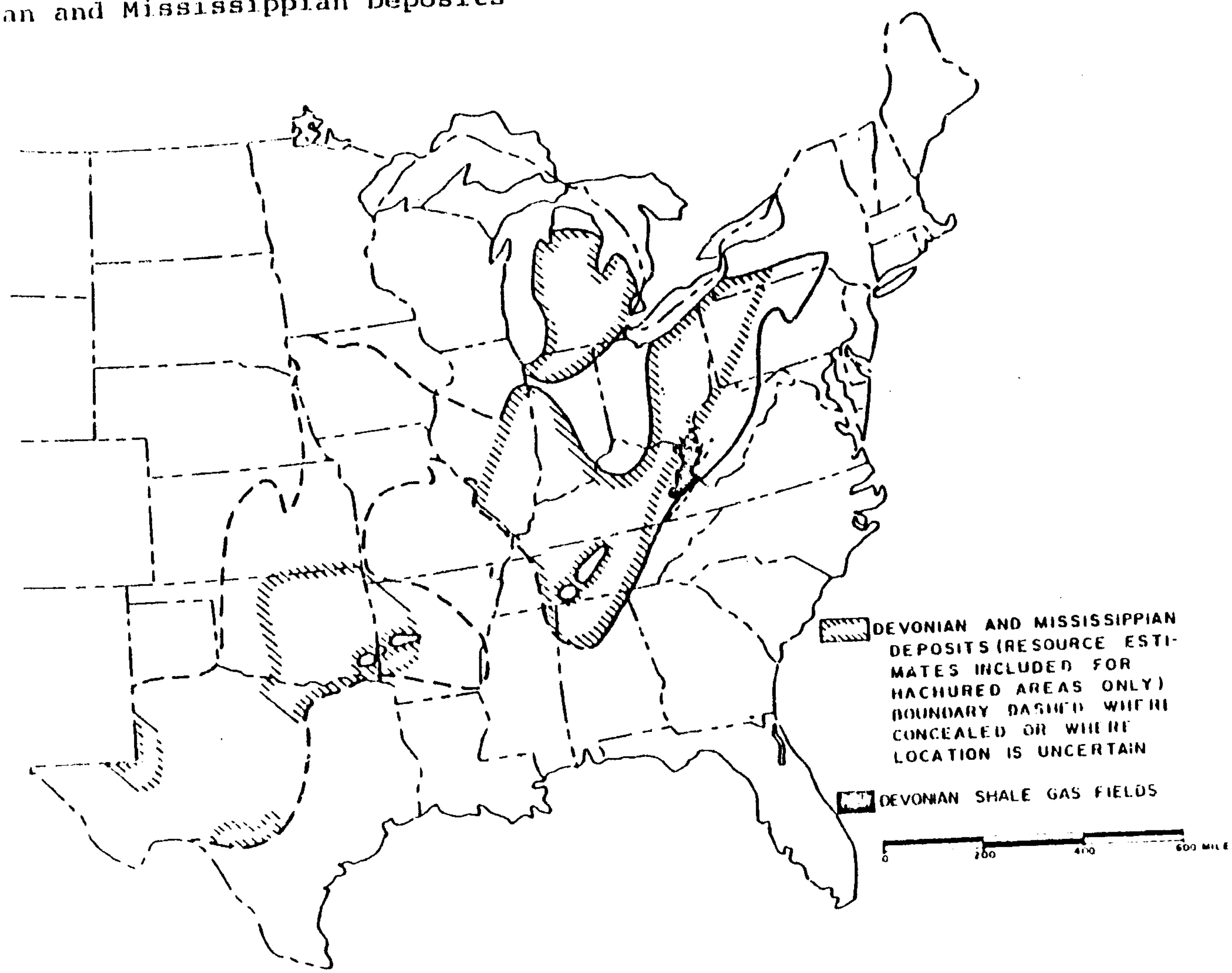
FIGURE 6.1

Devonian and Mississippian Deposits



Source: Modified from USGS (1965)

consider that these shales are known to be present under some 250,000 square miles, then it is obvious that they are a tremendous potential source of energy. (The total area including concealed and uncertain areas within both the solid and dashed outlines of Figure 6.1 is 550,000 square miles.)

An attempt has been made to determine the extent of Devonian Shale production and the number of producing wells. In West Virginia, Kentucky, and Virginia this was accomplished by using a key map divided into a system of two-mile grids. The number of wells in each square was then noted. From this, the total number of wells and the extent of the producing areas could be determined. The well count and well locations for Ohio were furnished by Mr. A. Janssens of the Ohio Geological Survey (Janssens 1975). The results of this study are shown in Table 6.1.

In other states some additional small fields and scattered wells have produced gas from the Devonian Shale. These have not been considered in this paper and it is not believed they are large enough to change materially the statistics given.

Of the 10,826 wells in which some gas was reported from the Devonian Shale, 1,211 or approximately 11 percent were either "plugged back" and produced from a more shallow horizon or plugged as a dry hole. Of the remaining 9,615 wells, 7,983 were drilled in the better portion of the Devonian Shale gas fields. The 1,632 wells remaining were either scattered, located on the periphery of the producing fields where two or less were drilled within a four square mile area, or are located in areas where the gas is being produced from shale at shallow depths. Well density within the fields ranges from 0 to 38 for each four square mile area with 7,983 wells located within densely drilled fields. These fields have a total area of 3,694 square miles with an average well density of one productive well for 296 acres. Shale well spacing is affected by several factors including: (1) competitive drilling where lease boundaries are densely drilled with few, if any, wells located in the interior; (2) areas of poor production resulting in dry holes or sparse drilling; (3) poor land titles resulting in tracts not being drilled; (4) culture and topography restricting the number of locations; and (5) spacing policies of individual companies.

As a result, although the calculated well spacing within the fields is 296 acres per well, the actual average spacing in the better portions of the fields is approximately 150 acres per well.

Devonian Shale gas production records and ultimate recoverable reserves are not available on all productive wells. There are several reasons for this: (1) the majority of the Devonian Shale gas is co-mingled in the well with production from Mississippian sandstones and/or limestones; (2) much of the production is from large leases

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TABLE 6.1

Estimated Reserves of Gas in Devonian Shale in Selected Areas

State	Total Productive Devonian Shale Gas Wells	Wells in Densely Drilled Areas	Scattered or Shallow Wells	Densely Drilled Areas in Sq. Miles	Sparsely Drilled or Shallow Areas in Sq. Miles	Total Productive Area in Sq. Miles	Ultimate Recoverable Reserves (MMcf) 300 MMcf Per Well*	350 MMcf Per Well*	400 MMcf Per Well*	Estimated Ultimate Recoverable Reserves Devonian Shale Only
East Kentucky	4,982	4,845	137	2,116	32	2,148	1,467,200	1,709,450	1,951,700	1,888,715
Ohio	1,500	300	1,200	146	281	427	210,000	225,000	260,000	215,850
Virginia	48	0	48	0	11	11	4,800	4,800	4,800	4,800
West Virginia	3,085	2,838	247	1,432	58	1,490	876,100	1,018,000	1,159,900	893,128
TOTALS	9,615	7,983	1,632	3,694	382	4,076	2,558,100	2,957,250	3,376,400	3,002,493

* In densely drilled areas; estimated 100 MMcf/well in scattered and shallow wells.

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and the wells are not individually metered; and (3) production records are not available for some of the early operations.

Because production records are not available, another approach to determine the total ultimate recoverable reserves from all past and present productive wells was used. The well counts shown in Table 6.1 were used for both the dense and sparsely drilled areas. Ultimate recoverable reserves of 100 million cubic feet (MMcf) per well were used in all cases for the sparsely drilled and shallow wells. Several areas were sampled and this seems to be a reasonable average for the total area.

The ultimate recoverable reserves for the densely drilled areas were estimated at three different recovery rates: 300, 350, and 400 MMcf per well. It is believed this range will cover the average recovery for these areas. Using the above method, the total ultimate recoverable Devonian Shale gas reserves range from 2.56 to 3.38 Tcf. My estimate is 3 Tcf.

For my calculations, I used 100 MMcf reserves per well for sparsely drilled and shallow wells; however, for the densely drilled fields, I used 430 MMcf per well in Eastern Kentucky, 355 MMcf per well in Ohio, and 360 MMcf per well in West Virginia. The reserves in the densely drilled areas were decreased 15 percent in West Virginia and 10 percent in Kentucky and Ohio to compensate for co-mingled gas produced from formations of Mississippian age. (This will be explained later).

We have shown in Figure 6.1 that some 250,000 square miles of area located between the Appalachian and Rocky Mountains are underlain by black shales of Devonian and Mississippian age. If 4,076 square miles of this area is productive at present, then only 1.6 percent of the potentially productive area is being used at present. It should be noted that an additional 300,000 square miles may be underlain by rocks of similar age and type. This area is not proved, however, and it is not considered in this paper.

Past and present gas well drilling is recovering only a minor percentage of the calculated gas present in the Devonian Shale in both solid and gaseous states. Shale wells are typically drilled on 150-acre spacing and are stimulated over an interval of 300 to 1,200 feet. A 1,000 foot interval generally contains approximately 600 feet of light colored shales and 400 feet of dark shales. If we assume 150-acre spacing and an average of 10 percent organic matter over the 1,000 foot interval with a yield of 1,300 cubic feet of gas per ton of shale by retorting, then the calculated gas in place is 552 Bcf per well. Assuming that the average shale well has ultimate recoverable reserves of 350 MMcf, the average recovery is only 0.06 percent of the calculated gas in place. If, on the other hand, only the 400 feet of black shale is productive, then calculated gas in place decreases to 221 Bcf and the recovery factor increases to 0.16 percent.

The above calculation deals with the recovery by retorting of the calculated gas in place. A more practical approach is to calculate the percent recovery of the total gas in place present in the gaseous state. Assuming 150-acre spacing, a 1,000-foot interval, 8 percent porosity, 700 psi rock pressure, and 40 percent gas saturation, the calculated gas in place is 10.67 Bcf per well with a recovery of 3.27 percent.

Assuming that only the 400 feet of black shale is productive, the gas in place is reduced to 4.27 Bcf with an 8.2 percent recovery.

The low recovery rate of gas in place is attributed to different modes of occurence of gas in the shale as illustrated in Figure 6.2. The gas which is free in pores and fractures, designated V1 in the diagram, and connected to the well bore is produced like a normal reservoir; that is, production rates are a function of permeability and volume in connected space. The gas adsorbed on the exposed shale surface is designated V2, and its production is related to the rate at which it is released from the shale. The gas within the matrix porosity is designated V3, and its production depends on the rate and depth of diffusion through the rock to a permeable connection to the well bore.

The vast majority of gas in a given shale area would be in the V3 class and under current methods most of this is not producible as the diffusion rate is extremely low.

It is important to remember that all gas including free gas not connected to the well bore would be classed V3. Therefore, we are actually producing a high percentage of V1, some percentage of V2 and a very small percentage of V3.

An examination of data obtained from retorting shale reveals that gas is physically adsorbed in the shale. (This is a necessary condition to permit 1,500 cubic feet or more of gas to be contained in a ton of shale.)

Adsorbed gas only occupies 0.5 percent as much space as free gas (Figure 6.3). One cubic foot of gas at 800 pounds pressure requires only 8 cubic inches of space if it has been adsorbed in shale.

It is believed that while stimulation by various fracturing techniques, used in other reservoirs, will increase the amount and rate of recovery by connecting more fracture systems to the well bore and exposing more surface area, the majority of the matrix gas (V3) will still not be produced. These techniques should be perfected for shale formations and in use within two years; they will help to alleviate the gas shortage to industry especially where it enters the intrastate market. These methods will not, however, have much impact on the overall domestic supply.

If a method can be found to release the matrix gas (V3), then this would have a great impact on the long-term domestic supply. With an energetic coordinated research

FIGURE 6.2

Relationship of Producible Gas to Shale

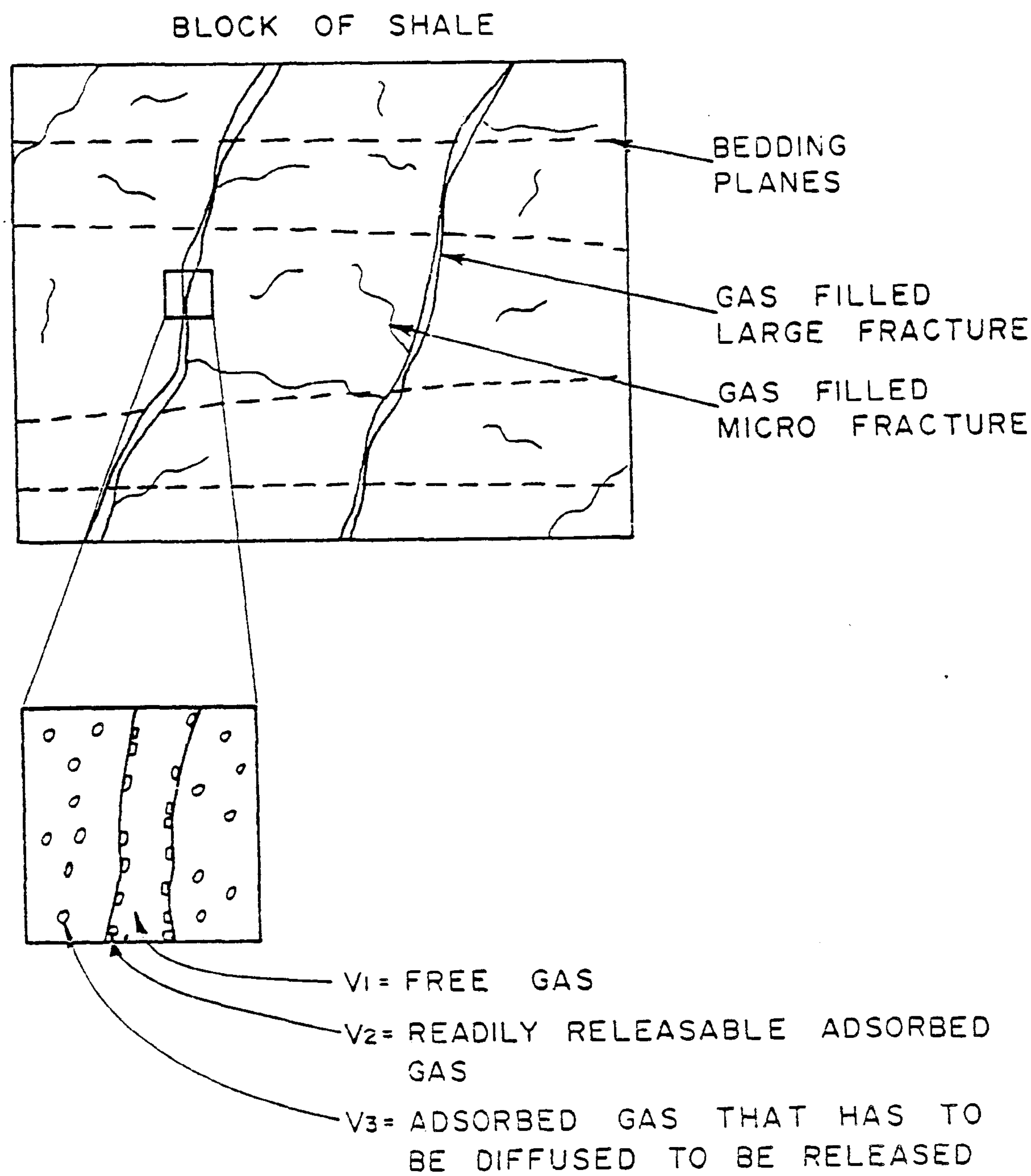

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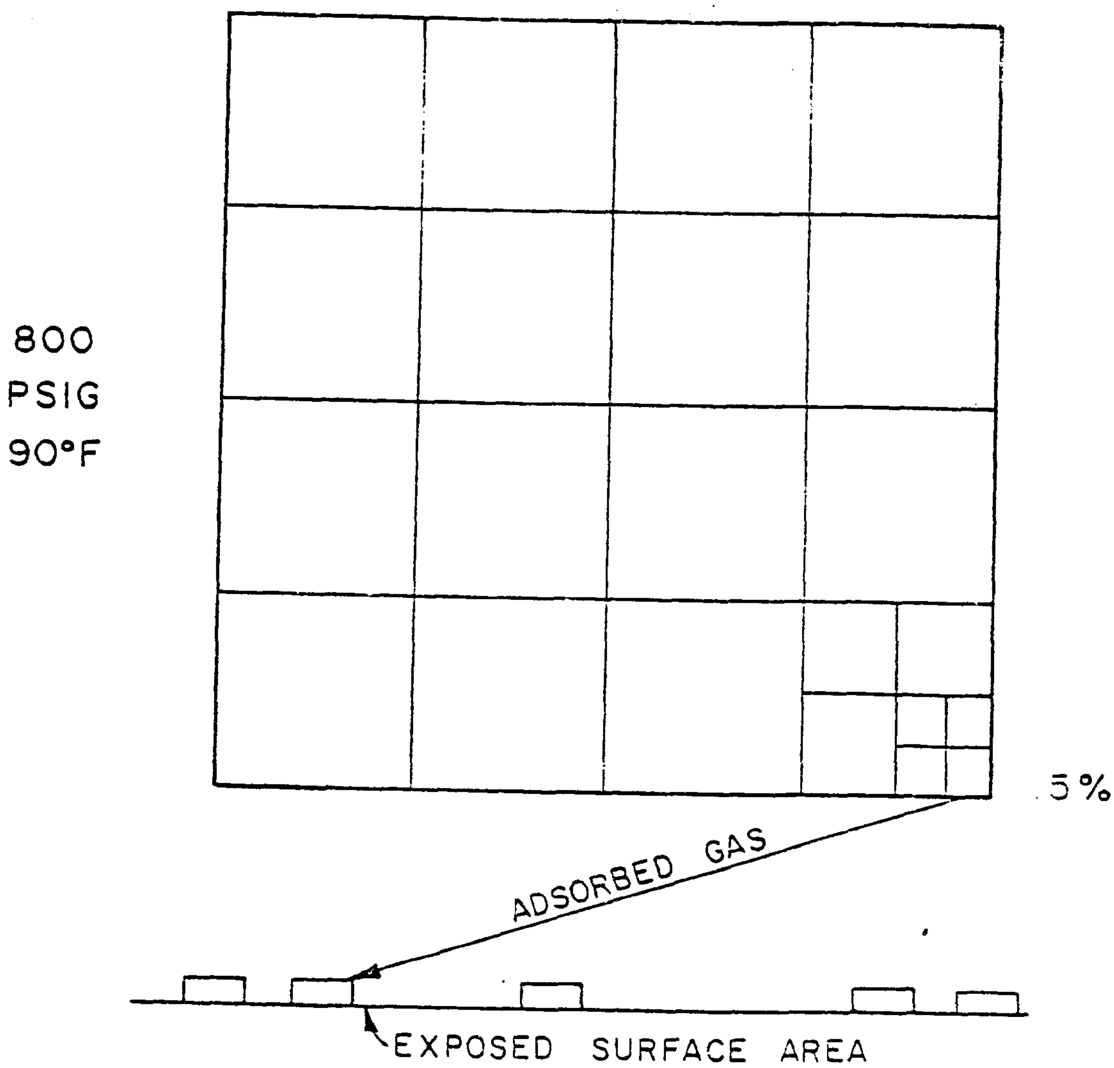
FIGURE 6.3

Volume of Space Occupied by Free Gas as Compared to Adsorbed Gas



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program by industry, federal and state governments, and various institutions, this may become practical within 5 to 10 years. The above statement assumes a price comparable to competitive energy sources.

It is suggested that investigations be initiated with two goals in mind: (1) to improve present methods or devise new methods of gas recovery which can be used immediately with existing equipment; and (2) to devise surface and subsurface methods for more complete recovery of the total energy contained in the shale. Some of these methods should recover the majority of the contained energy from gas, oil, and uranium. Investigations are suggested to determine:

1. The chemical composition of the various members of the shale.
2. The chemical composition of the various contained sources of energy.
3. The relationship of the shale matrix to the contained oil, gas, and uranium.
4. The mechanism of the desorption process and possible stimulation of this process.
5. The rate and depth of diffusion of gas through the shale matrix toward the permeable zones.
6. The possible use of bacteria to accelerate adsorption.
7. The various physical properties of the shale including microstructure, density, permeability, lithology, surface area, and porosity, both total and effective.
8. The amount and forms of energy contained in the various shale members.
9. The relationship between surface joints and fractures and reservoir fracture systems.
10. The relationship of tectonics to production of gas from shale.
11. The economics of drilling directionally-deviated shale wells.
12. The effect of the detonation of explosives within the formation.
13. The effect of thermal stimulation with particular regard to desorption and diffusion.
14. The potential and economics of massive hydraulic fracturing.
15. The potential and economics of multiple fracture treatments.
16. The effect of various fracture fluids including water, methanol-water, foam, gas, and various chemicals in fracture treatments.
17. The effect of various cleanup procedures.
18. The potential of various logging techniques.
19. The ideal well spacing in various areas using various stimulation methods.

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20. The potential, economics, and feasibility of mining along the outcrop and surface energy recovery methods.

Figure 6.4 depicts a typical driller's log of a Devonian Shale well located in southwestern West Virginia. The majority of the existing shale wells were drilled before electrical logging and this figure depicts the only information available to the researcher on the majority of the early wells. The section shown is from the top of the Big Lime (Greenbrier) formation of Middle Mississippian age to the top of the Corniferous Lime (Onondaga) of Devonian age. The majority of the existing wells were drilled by cable tool rigs. The 7-inch casing was set in the top of the Big Lime with the total depth being through the second section of Brown Shale. On most wells, the bottom white (Olentangy) and brown shale (Marcellus) sections, totaling approximately 500 feet, were not drilled because experience indicated that no gas production was to be expected from these zones.

During drilling operations, shows of gas are normally found in several of the formations. The drillers usually considered a show of gas to be anything less than 30 Mcf per day, therefore, some gas was usually entering the well bore from the Big Lime, Injun, Weir, or Berea formations before the top of the Devonian Shale was reached. After total depth was reached the total gas entering the well bore was gauged prior to shooting. The average flow before the shot was 60 Mcf or less per day, with the 24 hour test after the shot being typically between 150 and 400 Mcf.

Natural flows of gas are usually found scattered throughout the entire shale section; they normally cannot be correlated from well to well, even in the same area, and some of the better natural flows are found in the light colored shales.

The well was shot with explosives from the bottom to either the base of the Berea or the top of the Berea, depending on individual practice. However, caliper logs indicate the hole is enlarged through the Berea section even in cases where the top of the shot was at the base of the Berea; therefore, the Berea was stimulated to some degree in most wells.

Wells were considered combination wells when the driller reported a gas gauge in two or more formations. Where no gauge was reported from the Mississippian formations, the well was carried on the records as a shale well although some Mississippian gas was probably entering the well bore and was being produced and metered with the Devonian gas. Normally, the only time the gas was produced separately was when the gas flows from the Mississippian formations were large flows.

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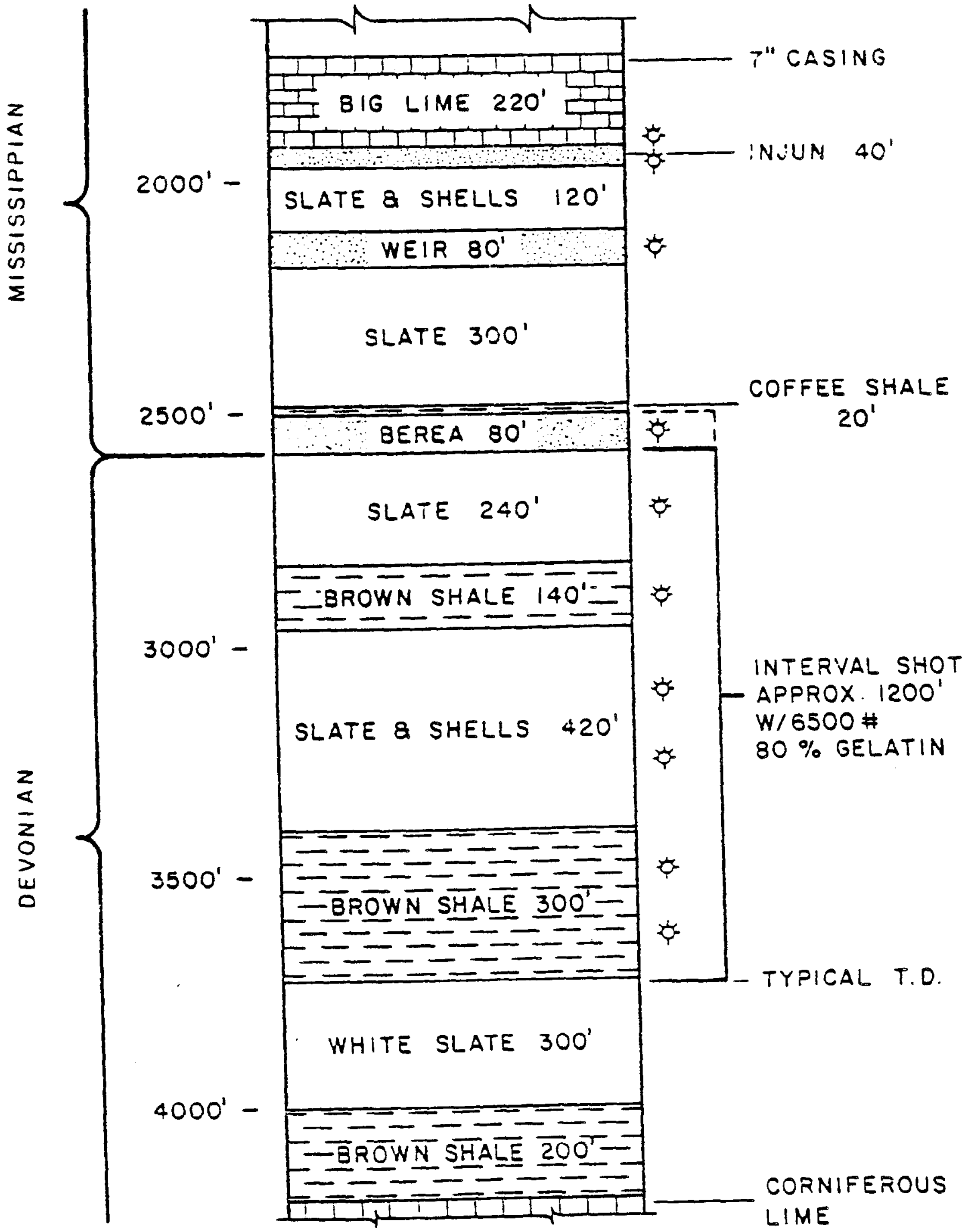
FIGURE 6.4

Typical Driller's Log of a Devonian Shale Well, Southwestern West Virginia



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Almost all reported gas production from Devonian Shale includes some gas produced from Mississippian sandstone or limestone. This fact should be considered in studies of Devonian Shale reserves. The percentage of Mississippian age gas recorded as Devonian Shale gas is estimated to be between 10 and 25 percent of the total. This percentage will vary according to area. For example, before the advent of fracturing, numerous shale wells were drilled in southeast Pike County, Kentucky, and Buchanan and Dickenson Counties, Virginia. After the advent of logging and fracturing, the operators began successfully fracturing the "Berea sand." They then began plugging the hole back to the base of the Berea in some of the low productive Devonian Shale wells to work over the Berea. It was found that the majority of the gas in these "Devonian Shale" wells had been coming from the Berea formation with very little from the shale. Since that time, most operators have stopped drilling the Devonian Shale section in that area. As another example, the Mississippian section is logged in most wells and evaluated for fracturing prior to plugging even though it has been open to the well bore during many years of "Devonian Shale" production. Many of the wells then have been fractured in one or more of the Mississippian horizons. This has resulted in economic production in numerous wells throughout the area. In some cases, these formations have still had original gas pressure in the rock, therefore, formation damage caused by drilling has prevented the outflow of gas from these formations during shale gas production. In most cases, however, the rock gas pressures of the Mississippian rocks have been lower than original, proving that Mississippian gas has been produced and included as Devonian Shale reserves.

Experience indicates that a conventional shale well will drain the free gas from at least the average well spacing of 150 acres and, in most cases, more than 300 acres. Later wells drilled in depleted areas, except for isolated cases, have had essentially the same gas pressures in the rock as the surrounding wells. It is obvious then that the gas being produced is the gas contained in permeable zones such as fractures, joints, bedding planes, and silty lenses. The gas in the matrix porosity is migrating to these permeable zones over a long period of time, but not fast enough to be economically produced by conventional shooting.

After successful stimulation methods are found, it is essential that these be proved as soon as possible and without waiting several years to obtain reservoir data for evaluation purposes before they are used on a regular basis. One possible method of doing this is as follows: drill a new well in a partially depleted area and extensively test the new and surrounding wells. The pressures at this point on both the new well and existing wells should be approximately the same. The new well should then be stimulated with the new method and retested. If at this

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point the gas pressure at the new well, and possibly in the surrounding wells, has not increased to or near original pressure, additional gas has not been released from the matrix and the new method is not successful. If, however, the pressure is at or near the original pressure then the method is successful in at least releasing a portion of the remaining gas. The new and surrounding wells can then be placed in production to permit calculation of the additional gas released. The new successful method could then be used throughout existing shale gas producing areas to yield additional gas reserves; this would use existing production facilities and deliver additional gas to the consumer in the fastest possible manner.

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