Proceedings of the 1989 Coalbed Methane Symposium,
The University of Alabama/Tuscaloosa
April 17-20, 1989

The 1989 Coalbed Methane Symposium

8913

A Strategy for Coalbed Methane Production Development Part III: Production Operations

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INTRODUCTION

Optimum development of a coalbed methane production field is dependant upon economically and technically successful wells capable of recovering the maximum amount of gas resource. To this end, various combinations of drilling, casing, completion and production techniques have been utilized in the different regions of the United States where coalbed methane has been produced. While the techniques may vary between regions (or within regions), the overall concept remains the same. All wells must account for the unique geologic and reservoir conditions present within coal beds if economic recovery of gas is expected. Since the inception of the coalbed methane industry in the mid-1970's, substantial improvement in the installation and operation of coalbed methane wells has occurred, primarily through the modification of conventional petroleum industry technology. This is reflected in the overall growth of the industry and improved well productivity.

WELL DESIGN

Prior to the initiation of a coalbed methane production operation, substantial characterization of the target formations must occur. As described in Parts 1 and 2, this characterization is the initial input into the well design, controlling to a large degree the type of drilling, completion, and production techniques used, and equipment required.

Geologic Influence - Since coal beds are the target formations for the production of gas, their occurrence, distribution, and size within the stratigraphic interval must be established prior to the installation of a production field. Selection of the producing interval(s) and evaluation of the bounding strata type determine the overall well depth and drilling techniques to be employed. For example, rotary-percussion (air) drilling is commonly used in stable, shallow formations and rotary-mud systems are employed for deeper, unstable formations. The thickness, number, and vertical distribution of the target coal beds are accounted for in the casing, cementing, formation access and stimulation practices used. Hydraulic stimulation design incorporates coal and rock properties along with in-situ stress regimes.

Reservoir Influence - The pressure and fluid saturation within the target coal beds impact drilling technique, as evidenced in the use of underbalanced drilling in relatively dry, low pressure coalbeds versus overbalanced drilling in high pressure, water or gas saturated coalbeds. Required hydraulic fracture dimensions for optimum gas recovery coupled with the reservoir properties of the target coal beds are also used during the design of the stimulation treatment.

DRILLING

Well Types - Currently three type of wells are used to recover methane from coal beds - horizontal, gob, and vertical (**Figure 1**). Horizontal wells are drilled from within coal mine workings and are usually associated with mine degasification activities. Gob wells are drilled from the surface into mined-out longwall blocks and are also associated with coal mine degasification activities. Vertical wells are drilled into virgin coal bed reservoirs for degasification and/or gas recovery purposes. The primary well type in current use for economic recovery of coalbed methane is the vertical well and will be the subject of this paper. Discussions of horizontal and gob wells can be found in Dixon [1], Kline [2], Finfinger [3], and Hargraves [4].

Drilling Techniques - The varying geologic and reservoir conditions within the coal basins of the U.S. has influenced the type of drilling used for coalbed methane wells. Generally, wells drilled in the eastern U.S., which target shallow coal beds (less than 2000 feet) in geologically older (Pennsylvanian) and more competent formations, employ simpler drilling techniques. This contrasts to more complex drilling practices used in wells drilled in the western U.S. targeting deeper coal beds, commonly overpressurized, in younger (Cretaceous), less competent formations.

Wells targeting the shallow eastern coal beds commonly use the rotary-percussion technique, with an air-water mist as the circulating medium (**Figure 2**) [5,6]. Experience has shown that the coal beds in the eastern basins (Warrior and Appalachian) are typically water saturated, low pressure, low permeability formations. Because the influx of formation water into the wellbore is minimal, air circulation can easily remove not only the cuttings but also any produced water. The higher penetration rate of rotary-percussion, which translate into reduced drilling costs, has therefore caused this type of drilling to become standard in the eastern basins. Additionally, since rotary percussion is an extreme underbalanced drilling situation using no mud system, formation damage due to mud filtrate influx is usually minimal. When formations are penetrated that produce large quantities of water, innovative practices combining air drilling with fluid drilling have been used [7].

While rotary-percussion is the choice for drilling coalbed methane wells in the eastern U.S., conventional rotary drilling with a fluid-based mud system is the approach used in the western U.S. (**Figure 2**) [6,8]. The occurrence of overpressured coal beds in the San Juan and Piceance basins necessitates the use conventional mud systems for well control. Even in normal-pressured situation, hole stability and fluid sensitivity within the less competent Cretaceous and younger formations of the west usually require the use of tailored mud systems. While fluid rotary drilling has been commonly used, special precautions to minimize formation damage in the coal intervals have become necessary. Balanced drilling systems have been determined to cause the least amount of filtrate influx into the coal beds, which are typically highly fractured [9,10].

Alternatively, some operators are using underbalanced drilling conditions, similar to that used in the eastern U.S., to minimize formation damage, enhance the well bore condition, and assist in the clean-up of the well [11]. This technique has been used to complete the most prolific gas producing wells in the San Juan basin. However, the production rates have not been directly linked to the underbalanced drilling procedure.

An important aspect of all coalbed methane wells is the creation of a large sump (or rathole) below the lowest target coal bed. This sump permits the placement of the artificial lift equipment below the lowest coal bed, thus enhancing the reduction in bottom hole pressure so critical in coalbed methane production. In addition, the sump is a convenient collection point for coal and formation debris (coal fines) which flow back into the wellbore. These sumps are typically 150 to 200 feet deep.

Drainhole Drilling - Drainhole drilling is a technology which only recently has been applied to coalbed methane wells. Vertical coalbed methane wells require some type of stimulation treatment to create a highly conductive fluid pathway through the coal bed. The ability to drill a long horizontal hole in a coal bed from a vertical wellbore therefore becomes an attractive alternative to a vertical well with a hydraulic stimulation (**Figure 3**). In addition, if the coal bed displays an anisotropic drainage pattern, the drainhole can be oriented to achieve better recovery. However, this technique has been attempted in the San Juan and Piceance basins with only limited success. A detailed discussion of the different drainhole techniques can be found in Logan [12,13].

Coring - An integral part of most coalbed methane development projects is the recovery of coal core for gas content, ash content, isotherm, and relative permeability determination (see Part 2). The recovery of core is achieved either as a part of the drilling of a production well or as a separate corehole [14]. When coring occurs during production well drilling, a conventional core barrel assembly replaces the bit assembly during the coring of the targeted intervals. This technique is the primary source of core in the western U.S. and is often used in conjunction with production well drilling in the eastern U.S. Alternatively, a corehole is drilled in which the primary purpose of the hole is to recover core. This commonly has the advantage of more rapid core recovery through the use of specialized wireline assemblies. However, limitations on the size of core and the depth of recovery usually limit this technique to the more shallow eastern coal basins.

COMPLETION

Completion Types - Three types of well completions are currently utilized in coalbed methane wells - open hole, cased hole, and open/cased hole (**Figure 4**). Each type has advantages under specific geologic and reservoir conditions.

Open hole completions have the advantage of minimal formation damage from cement invasion and reduced casing, cementing and accessing costs [8,15]. However, open holes reduce well control during stimulation and have the potential for hole loss due to collapse of the coal. In addition, control of water influx from non-coalbed aquifers adjacent to the coalbed is difficult in open-hole situations. Because of this, open hole completions are commonly used only when single coal beds or zones are

Cased hole completions have the advantage of specific control on the coal bed access point and maintaining wellbore stability [5,16]. This completion type has become the preferred method where multiple coal beds requiring multiple stimulations are the production targets. Conventional perforating tools or jet-slotting tools are used to access the coal beds. Disadvantages of cased hole completions are primarily related to possible formation damage during cementing operations. Lighter-weight cements, stage cementing, and specialized cementing tools have all been used to attempt to overcome the possible damage caused by cement. In addition, access point (perfs or slots) blockage during stimulation or later during production due to movement of the coal behind the casing may also reduce the effectiveness of cased-hole completions.

An alternative technique incorporates an open-hole completion for the deepest coal bed (or zone) with subsequent cased hole completion for any overlying coal beds (or zones) [16,17]. This technique has been proposed for coal beds of the Central Appalachian basin where the primary target bed (Pocahontas #3) is also the deepest.

Casing Design - The selection of casing size and type must incorporate the planned completion design, the anticipated production level (both gas and water), and the economic constraints of the project. Casing sizes in the 4-1/2 inch to 7 inch O.D. range are typically utilized in coalbed methane wells. Smaller casing sizes are both economically and operationally preferred. However, insufficient casing size may limit the effective dewatering of a coal bed reservoir, thus severely affecting ultimate gas production. Since most coalbed methane wells incorporate some type of artificial lift, sufficient clearance must be allocated for the tubing/lifting device. Stimulation design must also be incorporated in casing selection since the smaller sizes may limit the injection rate and/or fluid type.

As with casing selection, casing hardware (centralizers, shoes, baffle plates, packers, etc.) must be selected to be compatible with the planned cementing, stimulation, and production plan for the well. Since coalbed methane wells are typically low cost gas wells, minimum investment in casing hardware has been the norm. However, cost savings realized in minimizing casing hardware can often be offset by added formation damage or loss in well control.

Cementing - Cementing systems used on coalbed methane wells vary widely, depending to a large degree on well type (open-hole vs. cased-hole). Conventional Class A portland cement is typically used, often mixed with a pozzolanic material for strength enhancement with accelerators such as calcium or sodium chloride. This type of cement will have slurry weights in the 12 to 15 pound per gallon range, which may increase the possibility of formation damage to the coal beds in cased-hole completions. To over come the possible negative effects of cement influx into the coal beds, operators have used a variety of cement types and techniques to reduce the cement weight on formation. Nitrogen foam cements or cements with lightweight additives are often used when cementing across damage-prone formations. Stage cementing practices or not cementing to surface are also employed to minimize the cement slurry pressure on the coal beds [14].

Formation Access - Formation access refers to the technique of providing a physical pathway between the wellbore and the target formation. Access becomes a critical variable during stimulation of the coal beds and during production operations. During stimulation, the type of access controls the location and rate of fluid/solid injection, controls the amount and type of coal abrasion, and affects the final fracture geometry. Conversely, during production the access point controls the quantity of fluid (gas and water) that can move from the formation into the well bore.

The simplest procedure used is in an open-hole completion, where the target formation is directly in contact with the open-hole section of the wellbore. While this is provides the optimum access between the formation and the wellbore, hole stability and formation control problems exist with type of access. However, this access type is currently the most popular in the Warrior basin and is used extensively in the San Juan basin. To remove any possible formation damage caused during the drilling operation, hydro-jetting to expand the wellbore and remove any damage coal is often used. An extreme technique to remove damage coal is practiced in overpressured areas of the San Juan basin, in which the well is drilled underbalanced and permitted to flow naturally under limited wellhead control. This causes damaged coal (and coal fines) to flush off the exposed coal face in the wellbore, creating an enlarged wellbore free off formation damage.

When cased-hole completions are used, access between the target formation and the wellbore is via perforations or slots. Since these access points are critical during both stimulation and production, the selection of the access type, quantity, and orientation is of utmost importance. Perforations offer the most efficient and cost-effective method for accessing coal beds, especially when multiple coal beds are targeted. Perforations (jet-charge) have been used successfully in both eastern and western U.S. coal basins using conventional wireline-conveyed perforating guns. The number, size, and type of charge vary widely, but generally the entire coal bed thickness is opened with shot densities of 4 per foot. Alternatively, the number of perforations could be limited, especially when multiple coal beds are to be stimulated, resulting in a true limited-entry technique for stimulation control. As with conventional gas wells, most perforations are either performed in or washed with acid to clean up cement or

An alternative to perforations is jet-slotting, which uses a combination of water and sand (occasionally gas-charged) pumped through a 1/8 to 1/4 inch nozzle on a tubing string, which cuts through the casing and cement sheath. Normally, vertical slots phased at 90 or 180 degrees are cut across the total thickness of the coal bed. The slotting technique has been used extensively in the Warrior basin but has only been used with limited success elsewhere. This has been primarily due to the cost effectiveness of perforations, especially at deeper depths. Attempts at orienting the slots in the preferred stimulation or production direction have met with some success in shallow operations (1500 feet) in the Warrior basin [18].

Stimulation - Since coal beds must be dewatered as rapidly as possible to initiate economic gas production rates, hydraulic stimulations are usually required for economic recovery of gas. As with conventional gas reservoirs, many different treatment designs have been attempted. The designs employed by the various operators have attempted to take into account the unique characteristics of the coal bed reservoir. The created fracture must be both long and have high conductivity. High conductivity is required to effectively reduce reservoir pressure, thus initiating gas desorption from the coal.

In general, stimulation treatments use a water-based fluid with silica sand as the propping material. The varieties of fluids used range from fresh water through linear and cross-linked gels to water-nitrogen foam systems, with proppants ranging in size from 12/20 mesh through minus 100 mesh. Extensive research and development has occurred in the area of stimulating coal seams with results found in Jones [19], Diamond [20], Holditch [21], Hanson [22] and Zuber [23].

Because of the unique mechanical properties of coal beds, stimulation design must be modified from that commonly used in conventional reservoirs. Coal modulus is usually much lower than the surrounding strata, resulting in wider than expected fractures. Since many of the targeted coal beds are shallow (less than 2000 feet), especially in the eastern U.S., the lack of vertical and horizontal in-situ stress contrast can give rise to induced fractures with various orientations (vertical, horizontal, combination) [24]. In addition, the highly fractured nature of coal commonly results in multiple fracture planes plus the creation of "coal fines" during the stimulation process.

Since coal beds are typically thin when compared to conventional gas reservoirs, effective stimulations which remain totally in-zone are difficult to achieve. Several mine-backs of coal bed stimulation treatments have shown that the created fracture can remain in-zone or the fracture can penetrate the surrounding strata [20]. An alternative to maintaining the fracture in-zone, especially when many thin coal beds are targeted, is to contact all of the coal beds with a single stimulation treatment. This has been suggested when individual treatments for each coal bed would not be economically possible. Stimulation designs have been successfully implemented where numerous thin coal beds have been contacted by a single stimulation treatment (**Figure 5**) [22].

An novel stimulation technique has been proposed by Alain [25] in which a large cavity is created at the wellbore by jetting the coal. This technique, termed "Cavity Stress Relief Method", enhances the permeability of the coal bed through in-situ stress redistribution, rather than expanding the wellbore as in a conventional hydraulic stimulation. The process for drilling and completing wells in the San Juan Basin described by Weeden [11] appears to be similar to this technique.

PRODUCTION

Well Clean-Up - Following the completion of the stimulation treatment, most coalbed methane wells require a clean-up operation prior to initiating production. The technique employed varies, but the overall objective remains the same - 1) recover the maximum amount of fluid injected into the coal bed during the stimulation, 2) remove any debris (proppant, coal fines, excess cement, etc.) in the well created during completion, and 3) remove the maximum amount of formation water prior to initiation of artificial lift.

Initiation of gas production from coal beds is usually dependent upon lowering the formation pressure, normally through dewatering of the coal bed. The fluid volumes injected during the hydraulic stimulation must therefore be recovered before the initiation of the coal bed dewatering phase. A certain amount of fluid can be recovered naturally, due to residual formation overpressuring following the stimulation. Once formation pressures are reduced to hydrostatic or below, alternative techniques must be utilized to recover additional stimulation fluid. Swabbing or bailing is commonly used to rapidly remove large volumes in these situations. In the areas where shallow coal beds are targeted, however, it has been recognized that this method of fluid removal also causes substantial influx of proppant into the wellbore. This has been attributed to the low in-situ stresses of the shallow coal beds not effectively providing sufficient closure pressure to immobilize the proppant.

An alternative to swabbing and bailing that has been extensively used in the Warrior basin is to use high velocity gas (commonly air or nitrogen) flowing down a tubing string in the casing to blow the well dry [15]. This procedure rapidly recovers the stimulation fluid while not affecting the propped fracture. In addition, removal of debris is enhanced with this technique. This procedure is similar to that being used on the underbalanced well completions in the San Juan basin [11].

Further recovery of debris from the wellbore is often accomplished using circulated fresh water. The drawback to this technique is the possible influx of debris (coal fines, clays, etc.) into the formation causing damage.

Artificial Lift - Most coalbed methane wells require some form of artificial lift to recover the water that is produced by the coal beds. Only through effective and continuous dewatering will optimum gas production be initiated and sustained. There have been many instances where dewatering was not achieved and the subsequent gas production was severely affected. One important aspect of dewatering coal beds is that the produced water rate can vary widely with time. Normally, coalbed methane wells produce substantial quantities of water during their early life (<1 year) followed by a long period of stabilized production at a much reduced rate. The selection of the type of artificial lift equipment to be used must take into account this variable water production rate. In addition, the availability of power (electric, gas, or diesel) for the artificial lift system must be incorporated into the final equipment selection.

The most common artificial lift method used has been the sucker-rod pump. These pumps have the ability to lift substantial quantities of water economically in both shallow and deep coal bed settings. The produced water, especially during early well life, commonly contains entrained solids (coal fines and proppant). Sucker-rod pumps have been used successfully in these situations, removing both the fluid and the solids.

Gas lift in coalbed methane wells has been used in limited situations with limited success. The shallow coal bed depths in the eastern U.S. basins limit the effectiveness and economic operation of this system. In deeper settings, gas lift has been attempted and may play a larger role as development of the deeper coalbed methane resources

Progressive cavity pumps have been successfully utilized in shallow coalbed methane wells in the Warrior basin, primarily due their ability to handle solids effectively and their overall lower operating cost (when compared to sucker rod pumps) [15]. However, the ability of these pumps to operate at deeper depths in coalbed methane wells has not been documented.

SUMMARY

Since the economic success of a coalbed methane project is ultimately dependant upon the success of the installed wells, effective planning and correct implementation of the drilling, completion, and production program must occur. The unique geologic and reservoir properties of coal beds necessitates a specialized exploration and reservoir characterization program. Without this upfront knowledge, the drilling and production engineer are severely limited in their ability to install and produce economically successful wells.

Utilizing the results of such a geologic and reservoir characterization program, the engineer can then effectively design and install the optimum coalbed methane well. Throughout the development of a coalbed methane project though, continued interaction between the geologist, reservoir engineer, drilling engineer, and production engineer is required if the economic success of the project is to be realized.

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Figure 1

Types of Coalbed Methane Wells

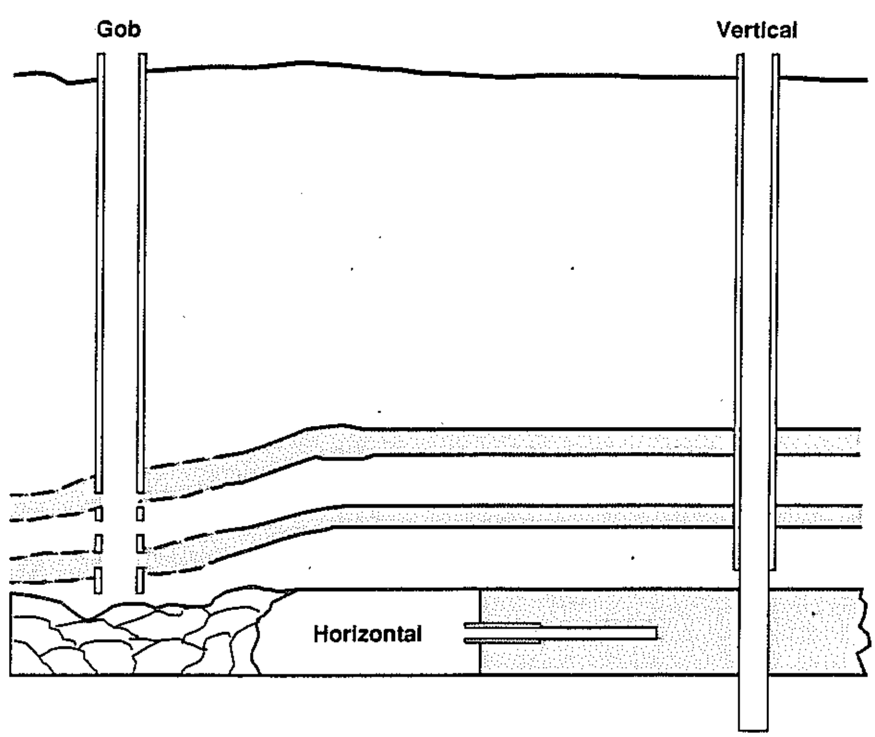


Figure 2

Drilling Techniques Used for Coalbed Methane Wells

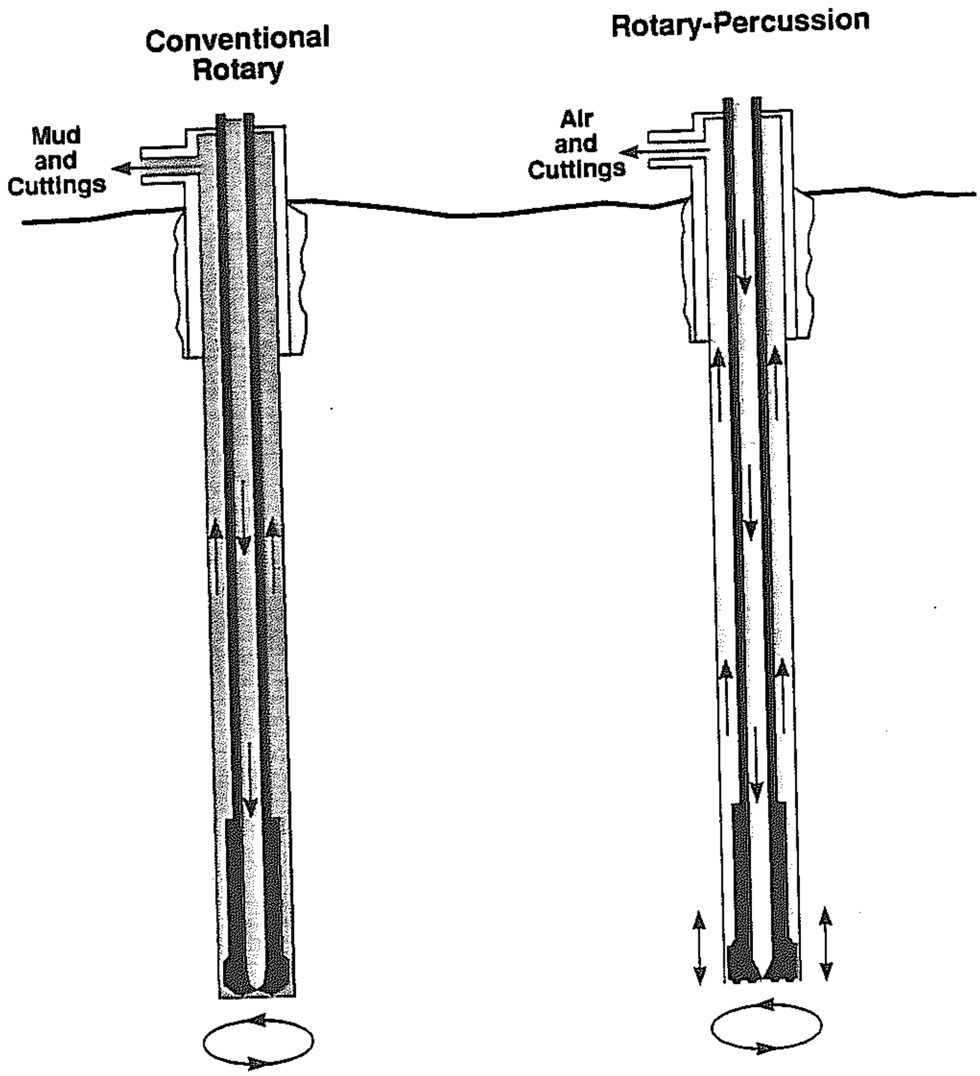
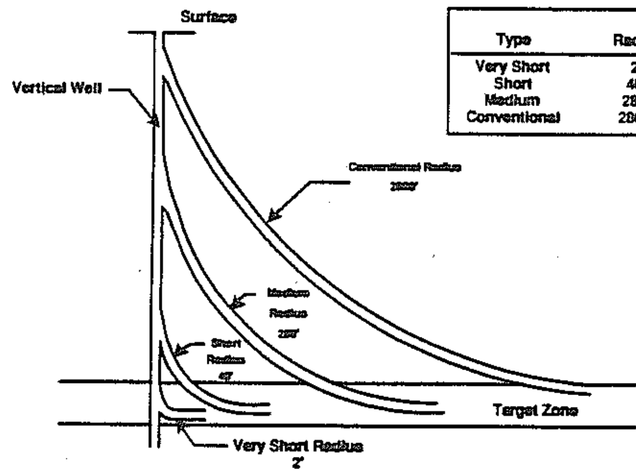


Figure 3

Drainhole Drilling Techniques (from Logan [12])



Type	Radius	Build Angle	Curve Length
Very Short	2'		3'
Short	40'	1.5°/ft	63'
Medium	285'	20°/100 ft	450'
Conventional	2800'	2°/100 ft	4400'

Figure 4

Coalbed Methane Well Completion Types

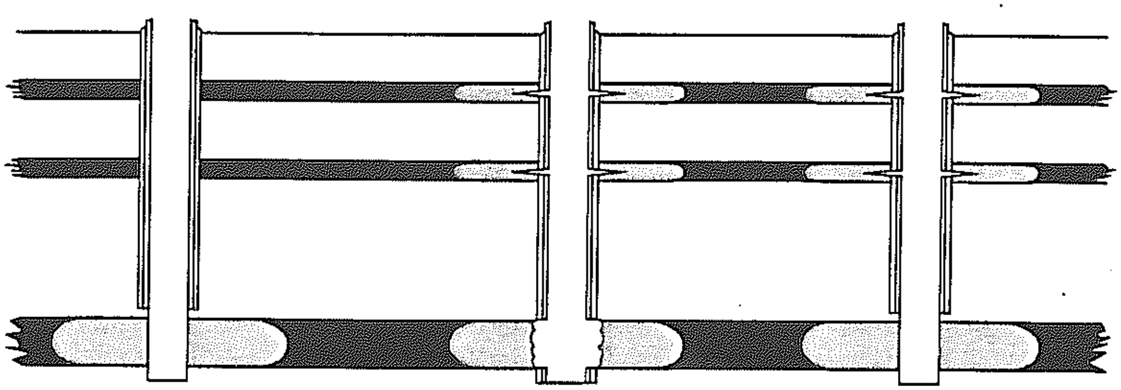


Figure 5

Stimulation Design for Thin, Multiple Coalbed
(from Hanson [22])