PRE-MINING DEGASIFICATION OF COAL SEAMS

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PREMINING DEGASIFICATION

- All premining degasification techniques can be classified into three broad categories:

✓In-mine horizontal drilling

✓Vertical wells with hydraulic fracturing

✓horizontal wells drilled from surface

- In very deep coal seams (deeper than 3000 ft), the horizontal boreholes can also be hydraulically fractured to enhance gas production and expedite degasification.
- Selection of a particular technique depends primarily on the gas contents and other reservoir properties.

IN-MINE HORIZONTAL DRILLING

- Generally, in-mine horizontal boreholes are used to perform two basic mine safety functions: reducing the in-place gas volume within the panel prior to mining and shielding active workings, especially development sections, from gas migration from the surrounding virgin gas reservoir.

- In-seam horizontal methane drainage boreholes are usually completed open holes, with a short segment (9–15 m) grouted to seal the end of the borehole near the mine workings.

- In high-permeability coals, in-mine horizontal boreholes can be used for shielding the gate road entries to maximize gate road development, for reducing in-place gas content of longwall panels, and thus for promoting maximum longwall mining advance rate.

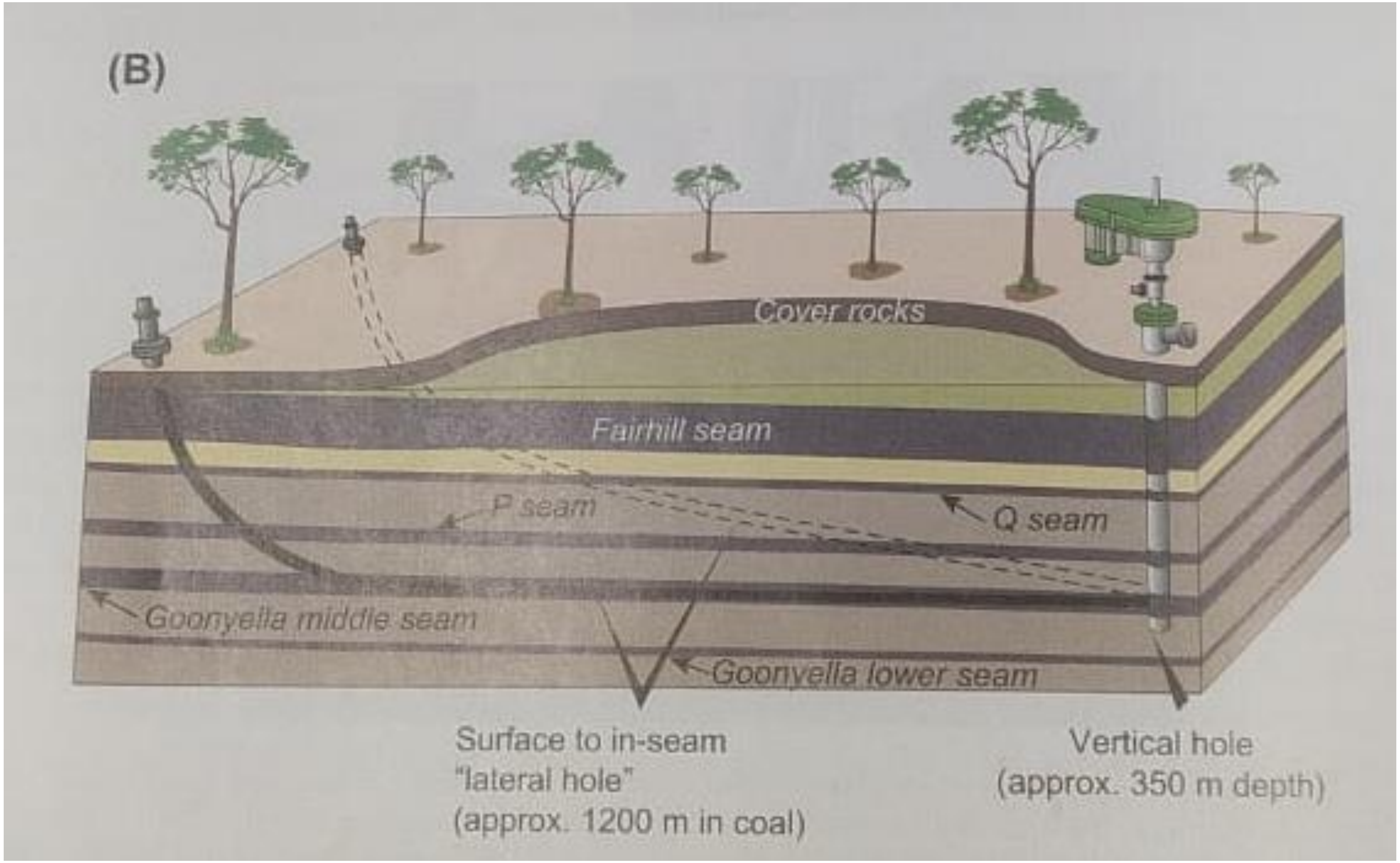
- In this technique, a borehole of 3-4 inch diameter is drilled to a depth of 3000 – 5000ft.

- Besides coal mine degasification, horizontal boreholes can be used for water drainage and advance exploration for faults, washouts, and other geological anomalies.

- The equipment used to drill long horizontal boreholes can be divided into four major groups: the drill unit, the auxiliary unit, the bit guidance system, and the downhole drill monitor (DDM).
- The drill rig provides the thrust and torque necessary to drill 3-4 inch diameter boreholes to a depth of 3000 – 5000ft.
- The auxiliary unit provides high-pressure water to drive a drill motor and flush the cuttings out. It also holds a gas and drill cutting separation system.
- The bit guidance system guides the drill bit up, down, left, and right as desired to keep the borehole in the coal seam.
- The DDM measures the pitch, roll and azimuth of the borehole assembly. In addition, it indicates the approximate thickness of coal between the borehole and the roof and floor of the coal seam by using a gamma ray sensor that measures radiation from the roof or floor.

Drill bit types

FIGURE 7.4 Representative drill bits used for drilling coalbed gas wells in the Powder River Basin in Wyoming, United States, showing various sizes. (A) 34.3-cm surface drill bit. (B) 22.2-cm longstring drill bit. (C) 15.9-cm drill-out bit. *Photographs courtesy of Tom Doll.*



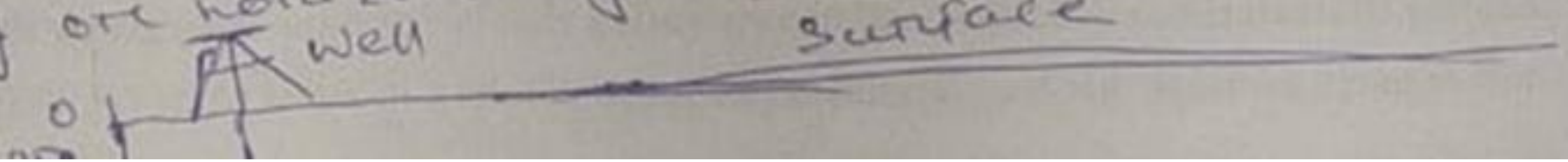
d (B) slant directional drillholes in front of coal mining in order to drain the coalbed gas from a vertical well in

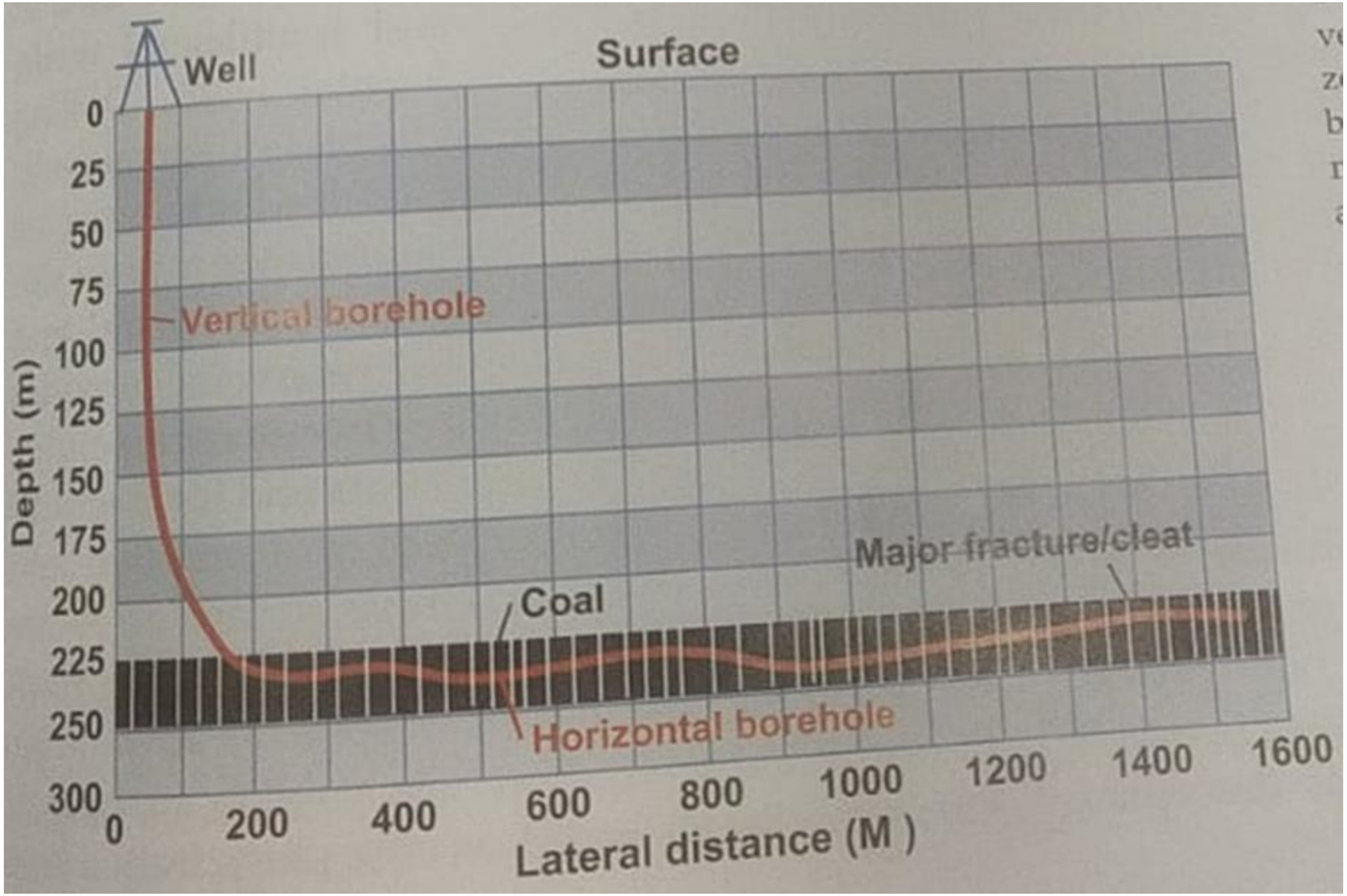
Vertical Drilling and Horizontal Drilling

way to horizontal wells. Vertical vs Horizontal

→ vertical wells are drilled from the surface straight downward into the overlying rocks above and into the target coalbed.

→ when the borehole is in the coalbed, it can be drilled laterally or horizontally for nearly 2000m, as shown in figure.





Schematic diagram showing a vertical well steered and drilled horizontally for about 1600 m parallel to the bedding plane of the coalbed in order to make maximum contact to the coal cleat and fracture systems.

laterally ... surface
figure.

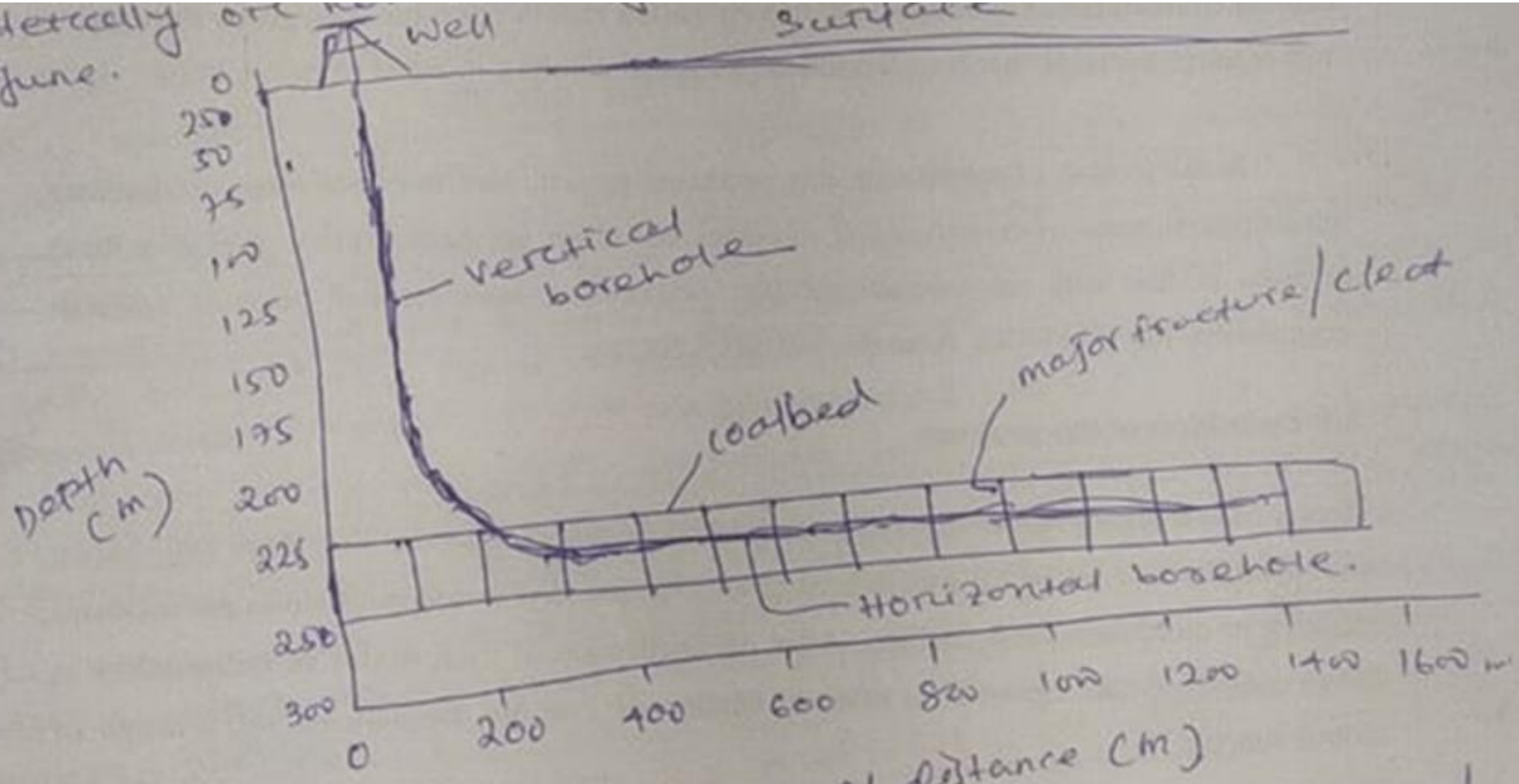


Fig. Schematic diagram of a vertical well steered and drilled horizontally for about 1600m parallel to the bedding plane of the coalbed in order to make maximum contact to the coal cleat and fracture systems.

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to the bearing ... to the ...
make maximum contact to the ...
fracture systems.

→ Underground coal mines commonly employ horizontal drilling technique from the coal face and perpendicular to the face cleat to maximize gas drainage in front of mining.
This technique is more efficient in draining gas compared to a vertical well, which has to be drilled for some vertical distance before reaching the coal bed.

- Most CBM wells are vertical. The commonly used methods for drilling vertical CBM wells are rotary percussion drilling and the conventional rotary drilling.
- The formation hardness determines the type of drilling method to be used. For softer formations the rotary method is used, whereas for harder formation, rotary percussion drilling is used for a faster rate of penetration.
- The most commonly used drilling fluids in coal are air/mist, aerated mud and formation water. The selection of fluid is dependent on the coal seam reservoir properties. To prevent formation damage while drilling, the coal is drilled underbalanced. This prevents the drilling fluid, chemical additives, and drilling solids from being injected into and plugging the cleat system of the coal. In the case of overpressured reservoirs, a slightly overbalanced, water-based drilling fluid is used to maintain well control.

  - (drilling fluid is *a mixture of clay and other chemicals with oil or water that is circulated around the drill bit in oil-well drilling in order to lubricate and cool the bit, flush rock cuttings to the surface*)
  - (*Formation water exists naturally in the rock all along, before drilling*)
  - *If hydrostatic pressure in a well is higher than the reservoir pressure, the difference is called overbalance pressure, or simply overbalance. Conversely, if reservoir pressure is more than hydrostatic pressure, the difference is called underbalance.*

→ The types of drilling techniques, vertical vs horizontal, utilized for coalbed gas production are controlled by ① lithology of the penetrated formations, ② thickness of the coal beds, ③ lateral continuity of coalbeds, ④ reservoir properties (e.g. fractures or cleats), and ⑤ geological structures of the penetrated formations (e.g. folded and faulted)

→ The strengths of the lithology of the formations dictate whether the vertical drilling of the coalbed gas well will utilize conventional rotary or rotary percussion drilling methods.

per-cus-sion
([illegible])

→ Soft rocks require conventional rotary drilling and hard rocks need rotary percussion drilling for rapid penetration.

→ ...izontal wells are more advantageous than the

... distance of

and ...
rapid penetration.

→ The horizontal wells are more advantageous than the vertical wells based on the following: ① longer distance of penetration of the coal, ② a larger foot-print in the reservoir, ③ flexibility of being oriented perpendicular to and intersecting the primary face cleats ④ more effective in highly fractured coal reservoir, and ⑤ wells can be extended beyond horizontal into multilateral wells.

→ Although horizontal wells provide longer distance and more effective means of coalbed gas recovery, the borehole does not provide maximum aerial coverage of the reservoir.

→ The most efficient gas desorption and recovery methods employ more and longer horizontal boreholes in order to cover large areas in coal beds. Thus the borehole to be used in this situation is multilateral wells, which are forms of horizontal wells.

Horizontal Drilling

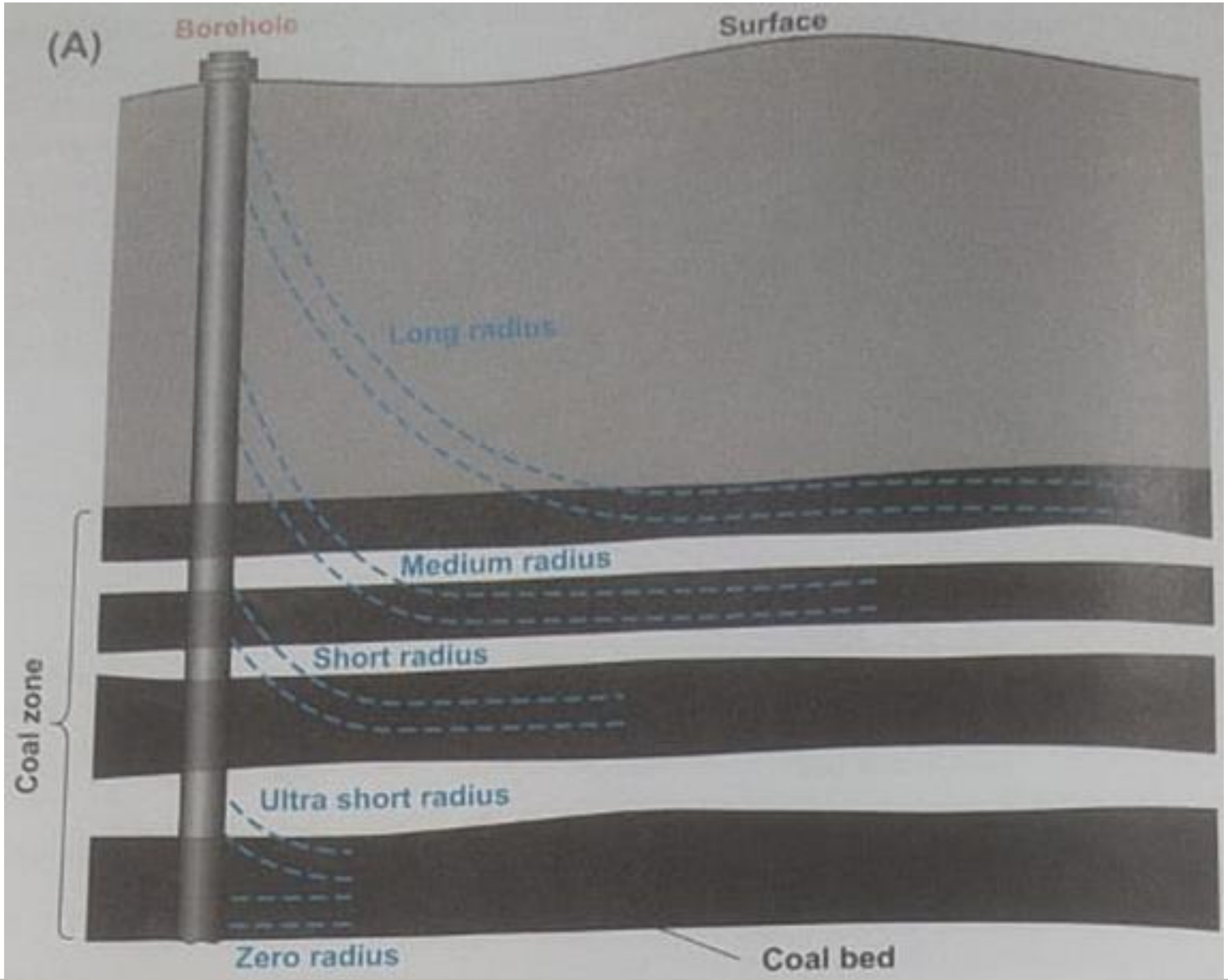
- Horizontal drilling is used to increase the footage of the production zone contacted by the borehole. Horizontal drilling increases the production rate and ultimate reserves recovered. The drilling equipment used for most horizontal wells is comprised of a drilling bit, positive-displacement motor (PDM), logging while drilling (LWD), measurement while drilling (MWD), non-magnetic drill collars, lateral “push” drill pipe (LPDP), heavy-weight drill pipe (HWDP) or drill collars (DC) used for weight, and drill pipe from surface (DPFS).

- Types of horizontal drilling are:

o Long Radius (LRH);

o Medium Radius (MRH); and

o Short Radius (SRH).



(A) vertical and horizontal drillholes drilled at various radii or arcs into horizontal coal

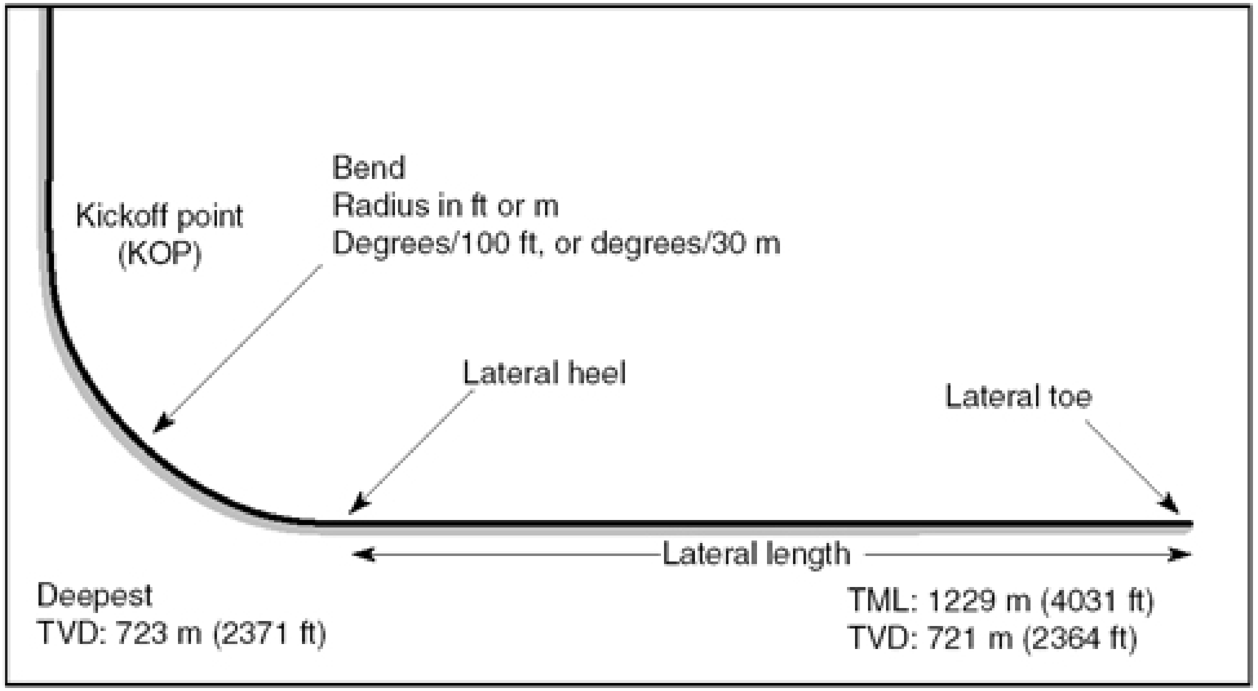
TABLE 7.2 Surface Directional Drilling Defined by Radius or Arc of Turn from the Vertical to Horizontal Wells

Radius Type	Radius of Turn (m)	Achievable Horizontal Distance (m)	Method
Zero	0	3	Telescopic probe with hydraulic jet
Ultrashort	0.3–0.6	60	Coiled tubing with hydraulic jet
Short	1–12	460	Curved drilling guide with flexible drill pipe; entire string rotated from the surface
Medium	60–300	46–1525	Steerable mud rotor used with compressive drill pipe; also conventional drilling can be used
Long	300–850+	600+–12,000+ (the latter is a record)	Conventional directional drilling equipment used; very long curve length of 850–1350 m needed to be drilled before achieving horizontal

m, meter; +, plus.

- Horizontal wells have a kick-off point (KOP), a directionally drilled curve section to an inclination within the range of 70° to 110°, depending on the dip of the coal, and a lateral section. The lateral section is drilled while changing the true vertical depth (TVD) of the well and the wellbore direction by adjusting the inclination and azimuth, respectively. Several types of CBM horizontal wells may be drilled (see Table).

- MRH profiles are generally the design of choice, with the exception of smaller hole sizes and drilling tools that can accommodate an SRH curve. MRH designs cover the widest range of build rates (6°/100' to 40°/100') and can be drilled using most common drilling tool sizes.

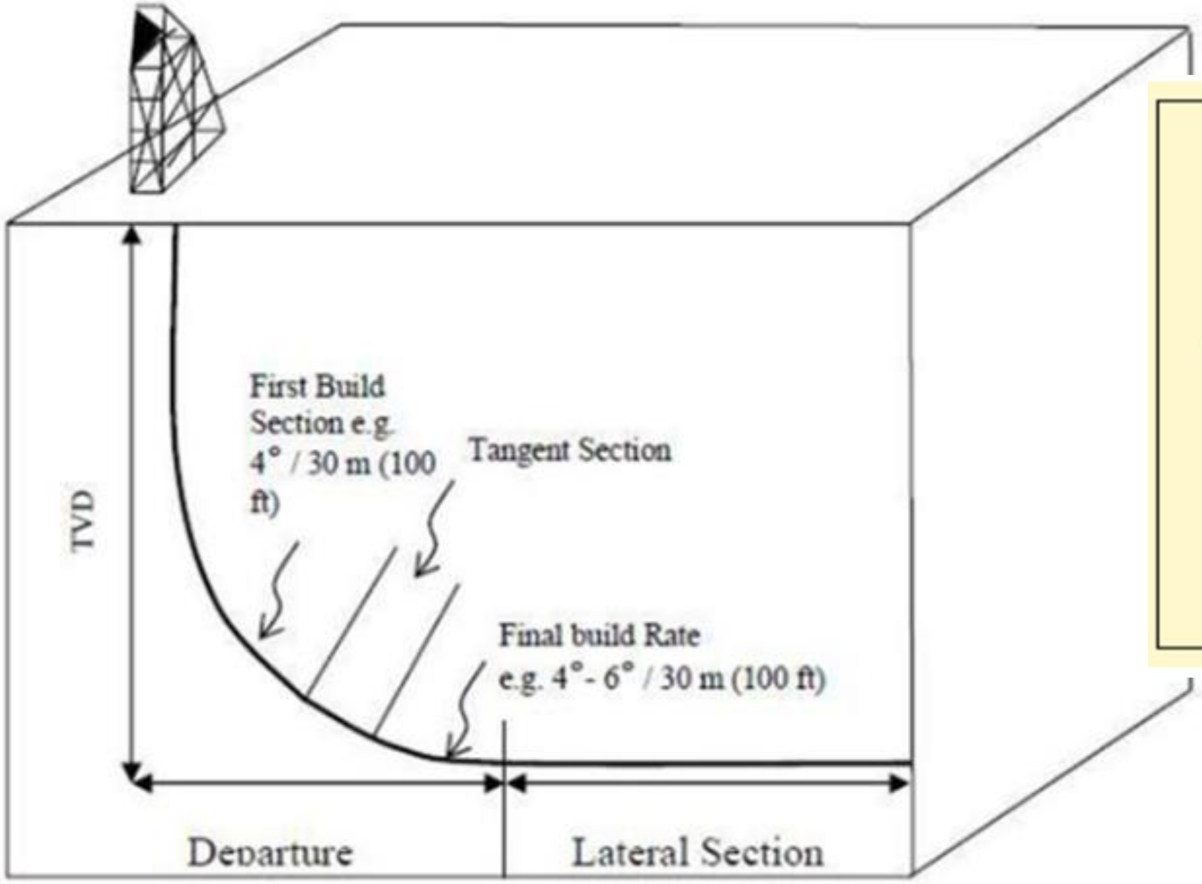


Build rate is the rate, measured in degrees per unit length, at which the well path of a [horizontal well](#) moves through the bend (curve) from vertical or high-angle to the desired low-angle or horizontal attitude.

Horizontal Wells

In practical applications, horizontal wells are high angle wells with the inclination angle in the range of about 80 deg to 100 deg. An ideal horizontal well, as the name indicates, the inclination angle is equal to 90 deg.

Kick-off point or kick- off depth is the vertical depth from which wellbore is given deflection in a particular direction with specific build-up rate.



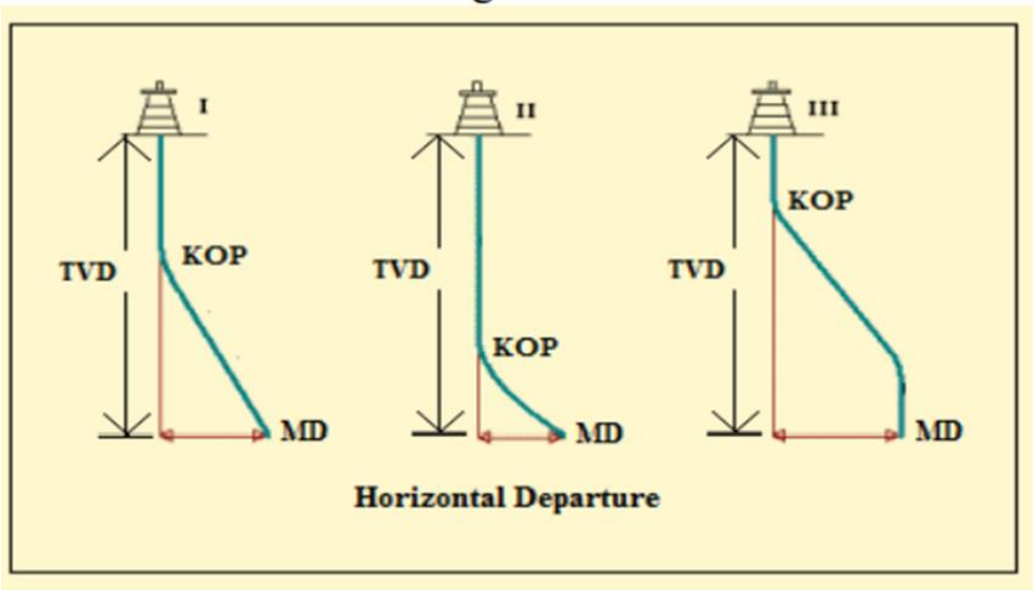
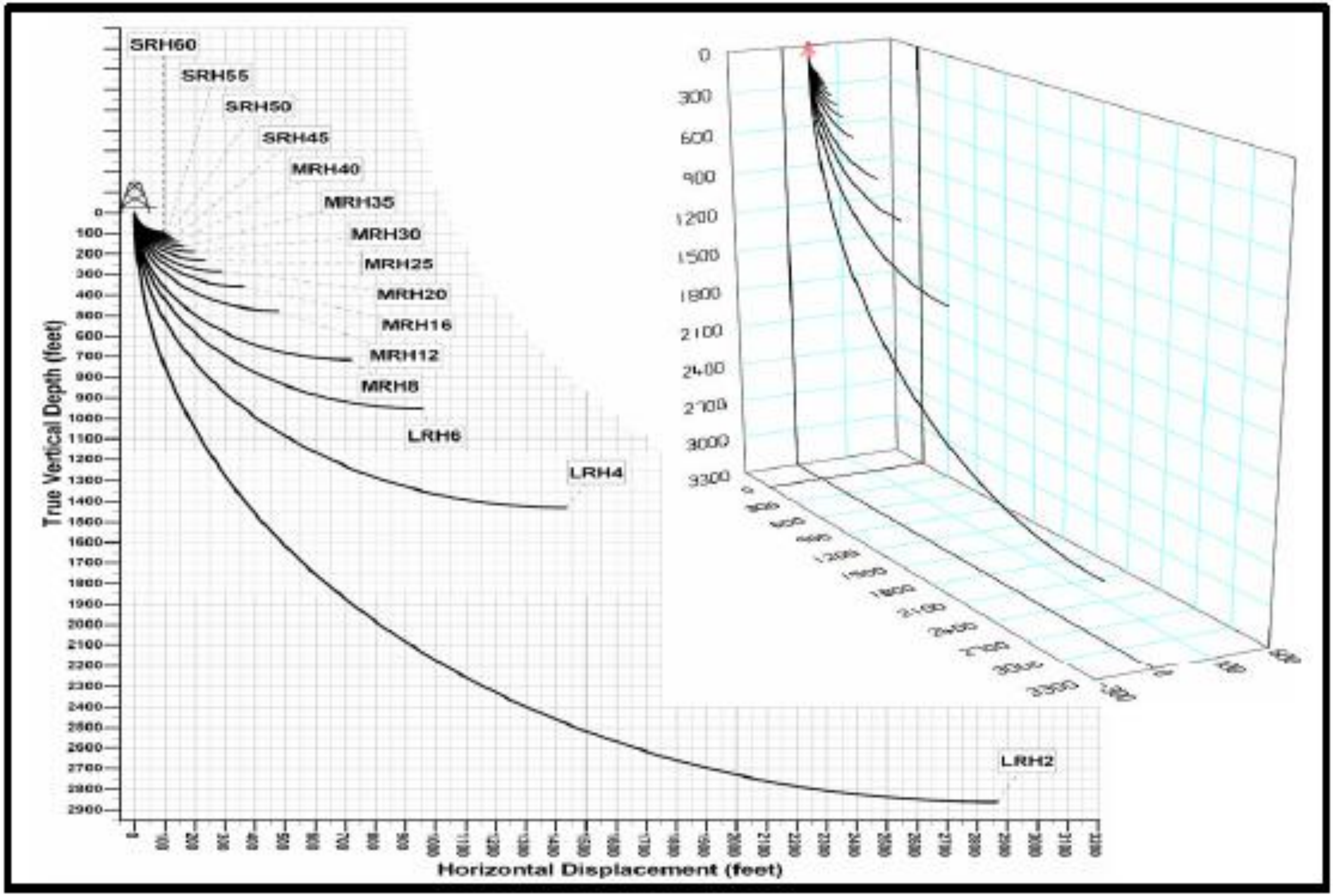


Table : Classification of horizontal wells and well specifications.

Horizontal Class	Horizontal Class Identifier	Horizontal Build Rate deg. / 100’	Hole Radius (feet)	Wellbore Size Diameter
Long Radius (Up to 6°/100')	LRH2	2°/100'	2865	8-1/2“ 6-1/2“ 4-3/4"
	LRH4	4°/100'	1432	
	LRH6	6°/100'	955	
Medium Radius (7°/100 to 40°/100)	MRH8	8°/100’	716	
	MRH12	12°/100’	477	
	MRH16	16°/100’	358	
	MRH20	20°/100’	286	6-1/2“ 4-3/4"
	MRH25	25°/100’	229	
	MRH30	30°/100’	143	
	MRH35	35°/100'	164	4-3/4"
	MRH40	40°/100’	143	
Short Radius (40°/100 to 60°/100)	SRH45	45°/100’	127	
	SRH50	50°/100’	115	
	SRH55	55°/100’	104	
	SRH60	60°/100’	95	

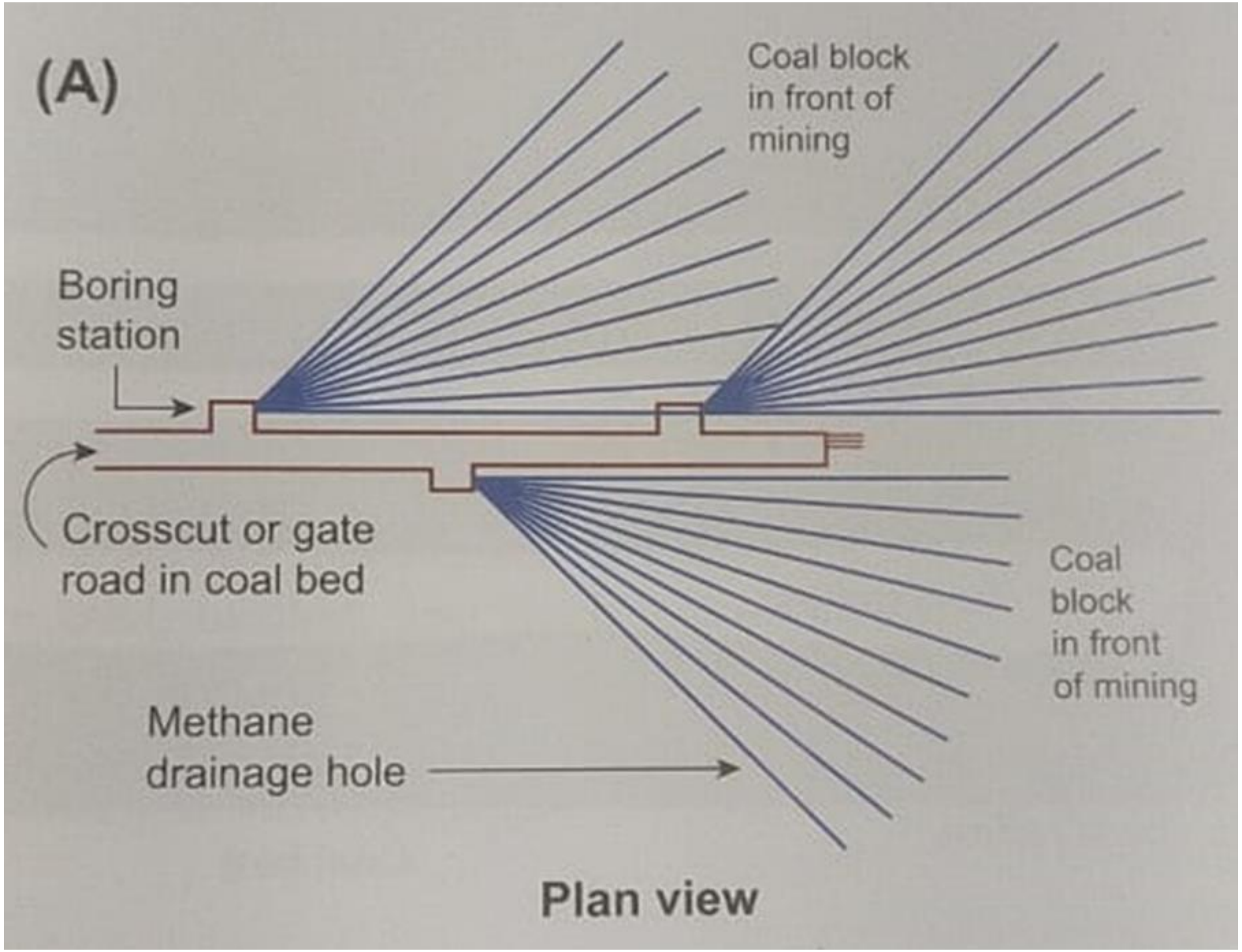
- LRH design is not suitable for CBM and many other unconventional horizontal drilling applications because the KOP above the desired lateral TVD is in excess of 950 feet (hole radius), as is the distance from the surface location to the start of the lateral section in the desired reservoir zone (**Figure**). This excessive distance impacts the well's ability to produce and limits the lateral footage able to be drilled because of additional geological zones exposed in the curve. In addition, the extra distance on the build portion of the well is much longer. This increases the section of high contact forces on the drilling assembly.

- Ultra SRH wells have curve build rates greater than 60°/100' (radius less than 95 feet), and are not used for CBM wells because of the limited lateral section achievable. Ultra SRH profiles are complex and are expensive to drill, requiring specialized equipment.


SRH60
SRH55
SRH50
SRH45
MRH40
MRH35
MRH30
MRH25
MRH20
MRH16
MRH12
MRH8
LRH6
LRH4
LRH2
True Vertical Depth (feet)
Horizontal Displacement (feet)

LATERAL AND MULTILATERAL DRILLING

- Although horizontal wells provide longer distance and more effective means of coalbed gas recovery, the borehole does not provide maximum aerial coverage of the reservoir.
- Conceptually, the most efficient gas desorption and recovery methods employ more and longer horizontal boreholes in order to cover large areas in the coalbeds. Thus, the borehole to be used in this situation is lateral and multilateral wells, which are forms of horizontal wells.
- Drilling lateral and multilateral wells off horizontal wells multiply the recovery of coalbed gas reserves from a much larger drainage area than in just a single horizontal well.
- Lateral and multilateral drilling of coal reservoirs provides more contact to cleats and/or fractures perpendicular to bedding.
- Lateral boreholes can be drilled into various directions and patterns from an access borehole such as lateral to right and left of the original horizontal well as shown in figure.
- In cases where a number of thin coal seams are to be accessed, multiple lateral wells will provide greater production than a vertical well.



Schematic plan view in an underground coal mine of coalbed gas drainage holes drilled from boring stations in a gate road (tunnel at the back of a longwall panel for degassing before mining starts) in front of mining along the bedding plane of the coal.

- In Fig. 6A, multilateral horizontal boreholes are drilled from a single drilling location in the headgate entry to reduce the gas content of the coal volume in the panel area before mining. In Fig. 6B, boreholes drilled from various locations in the mains extend into multiple panel areas to drain the gas in a larger area before mining commences.
- Multiple wells can be connected together as shown in Fig. 7 for gas gathering and transportation within the mine.
- Horizontal, lateral, and multilateral wells are more effective in flat lying than in folded, faulted, and thick coalbeds.
- The disadvantage of drilling horizontal, lateral, and multilateral wells is that it increases the cost of coalbed gas development.

- Used in lower permeability or thinner seams (thickness-<2m)

Single lateral

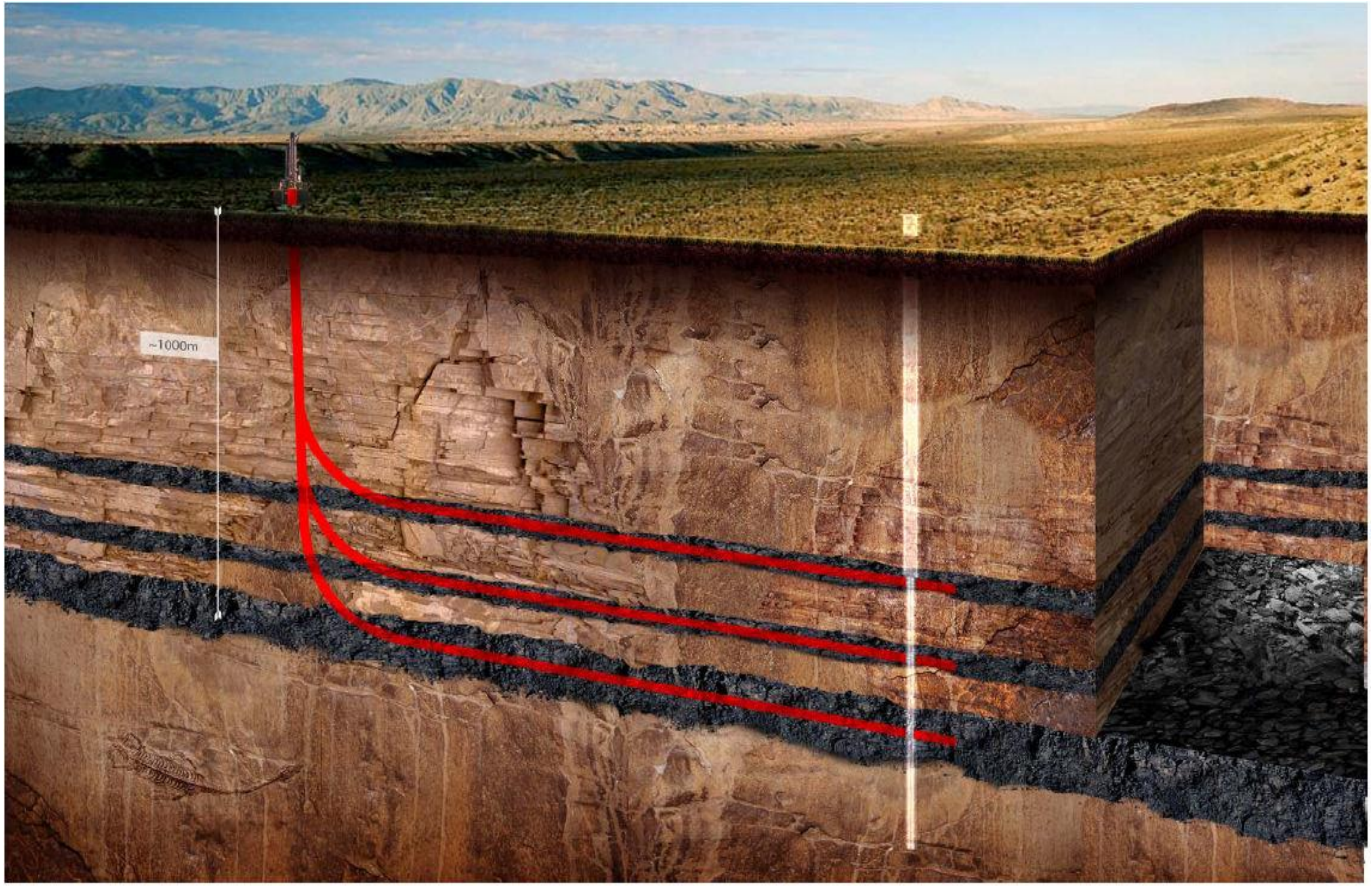
- one horizontal borehole

Multi-lateral

- two or more laterals in a seam

Multi-lateral stacked

- two or more laterals in separate seams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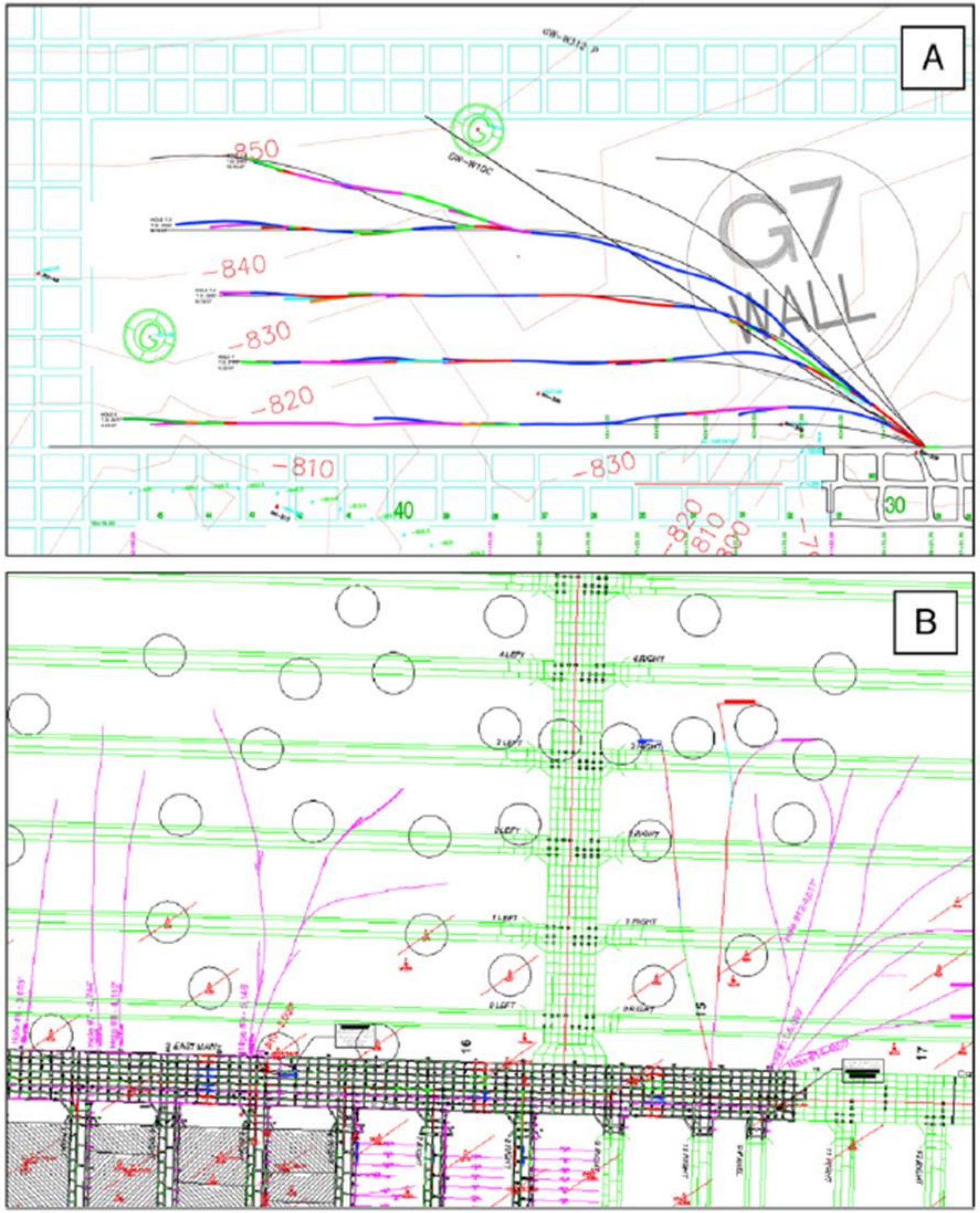


Fig. 6. Examples of using horizontal boreholes to reduce the in-place gas content of longwall panel (Bohan, 2009). Courtesy of REI Drilling.

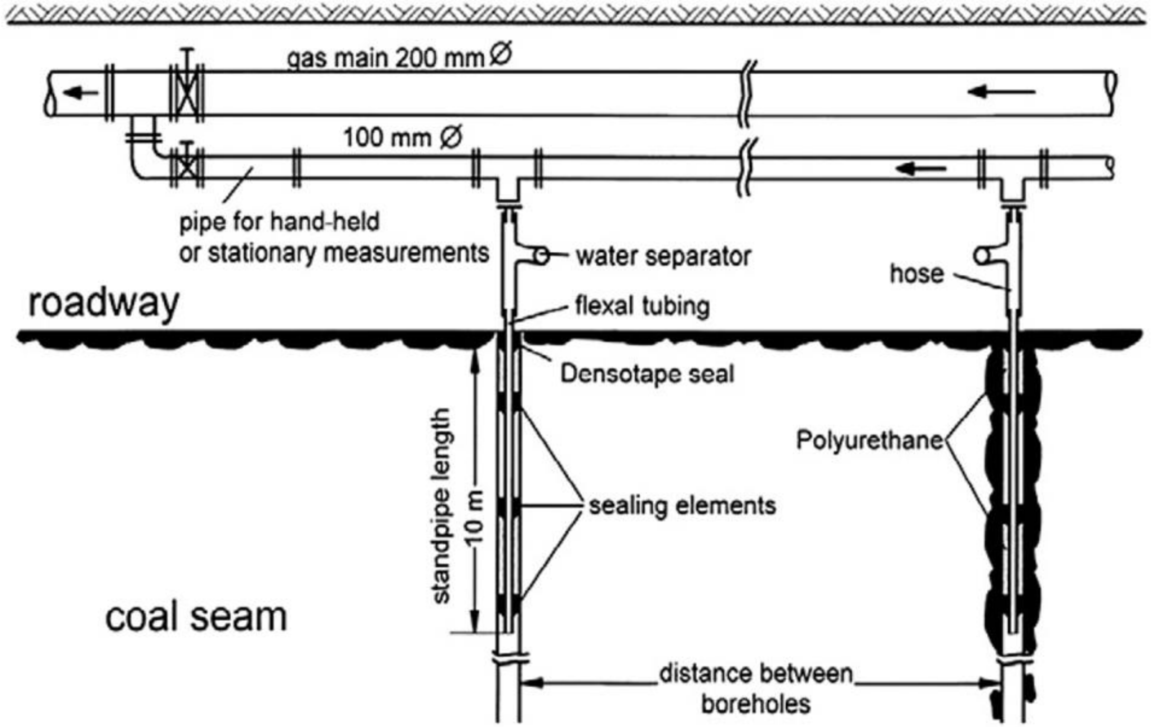


Fig. 7. An underground connection schematic of pre-drainage boreholes (Noack, 1998).

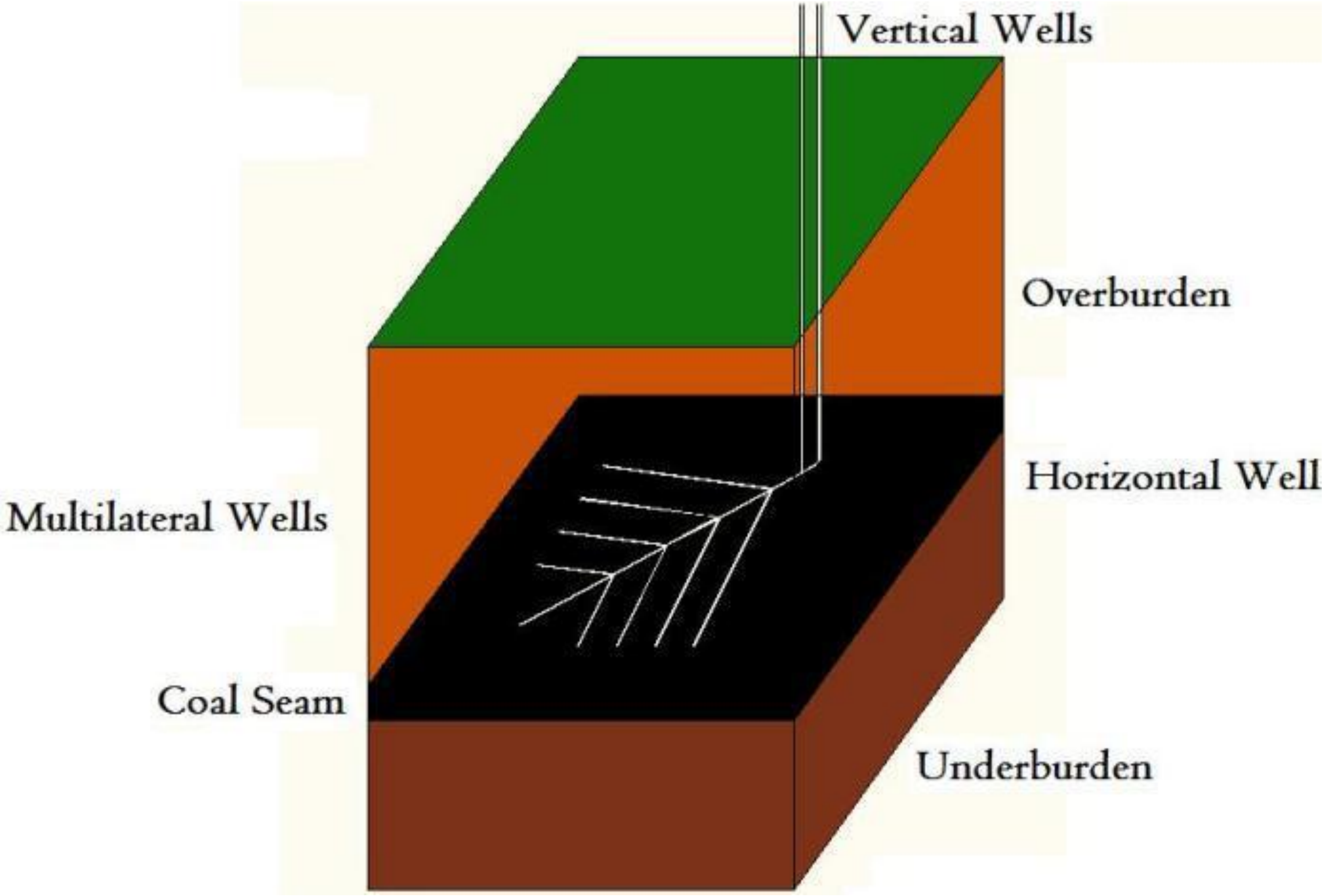


Figure : Multilateral Horizontal Well

Pinnate Wells

- Pinnate pattern, multilateral wells have proved very successful in producing coalbed gas from low-permeability coals.
- Pinnate wells may have a 20-fold increase in production rate, compared to fracture-stimulated vertical wells.
- The pinnate well pattern was developed by CDX drilling to produce CBM from low-permeability coals. Some advantages of pinnate wells are that:

✓Wells can drain up to 2000 acres from a single drill pad

✓Gas is produced immediately

✓Peak gas production is reached quickly, unlike a vertical wells in CBM reservoir

✓Wells can drain a reservoir in 2 to 4 years

✓Gas recovery is high (80 to 90%)

✓High gas flow rates can be achieved

- But these wells are not suitable in high permeability coals.

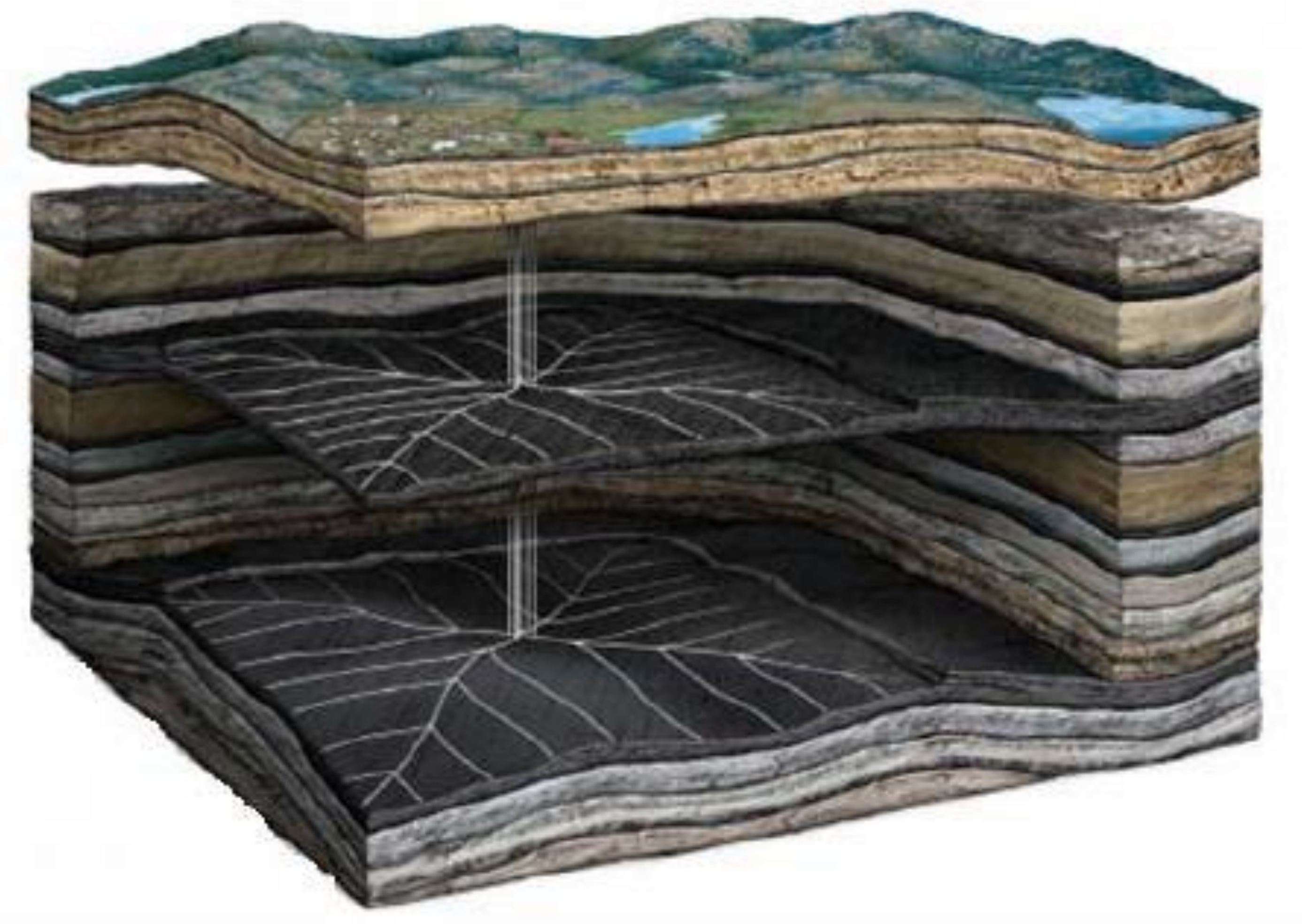


Figure : Pinnate pattern drilling

4.2 Methane Emissions

It is safe to assume that all coal seams are gassy because coal and methane in coal are syngenetic in origin; that is, they are derived from the same plant material. The gas content of coal seams varies depending on the rank of coal and the depth of coal seam. Globally, coal seams can be divided into three categories depending on the depth and their gas contents in ft^3/ton as shown in Table 4.1.

Table 4.1 Gassiness of Coal Seams [1]

Category	Depth (ft)	Gas Content (ft^3/ton)
Mildly gassy	500 or less	100 or less
Moderately gassy	500–1500	100–300
Highly gassy	1500–3000	300–700

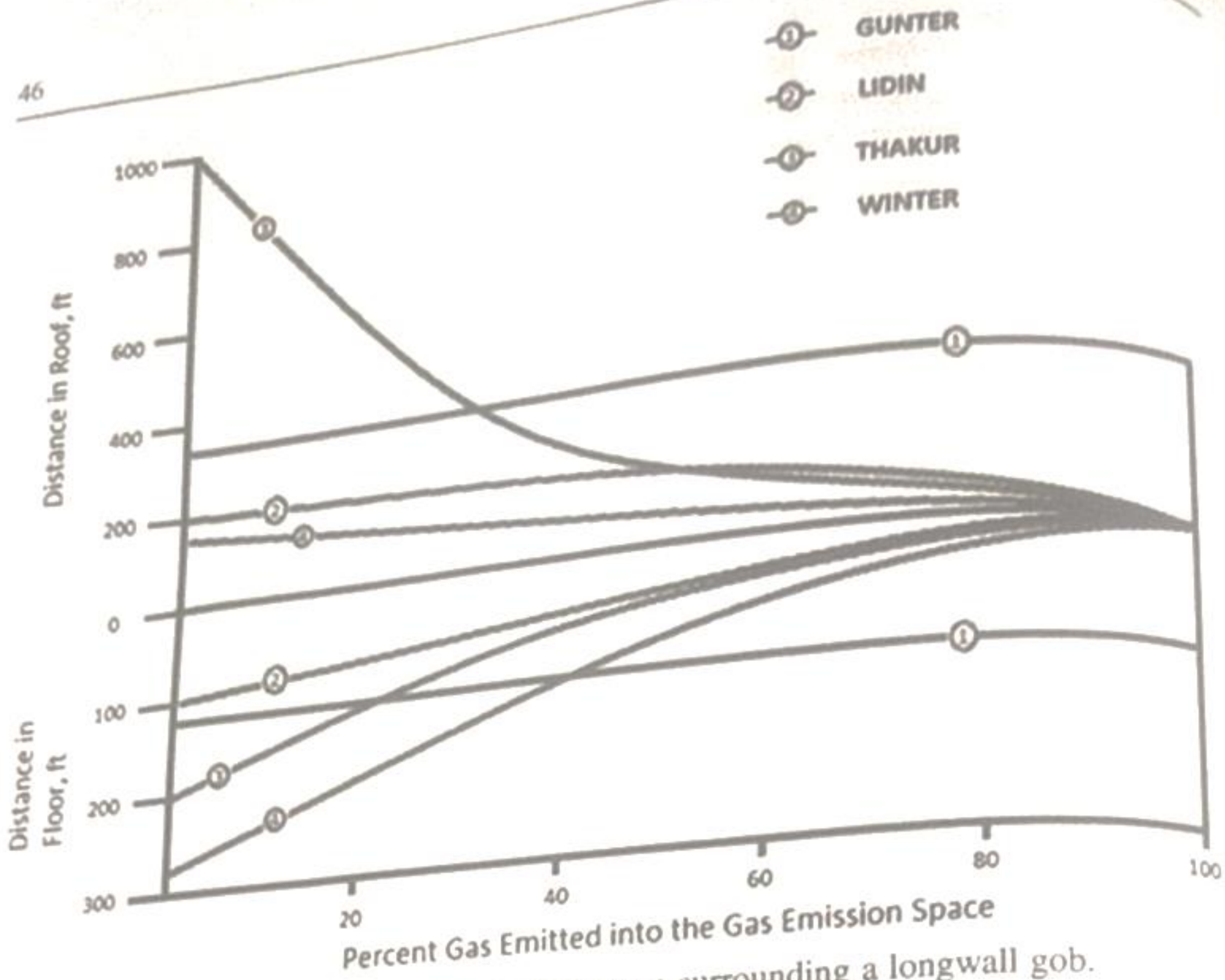
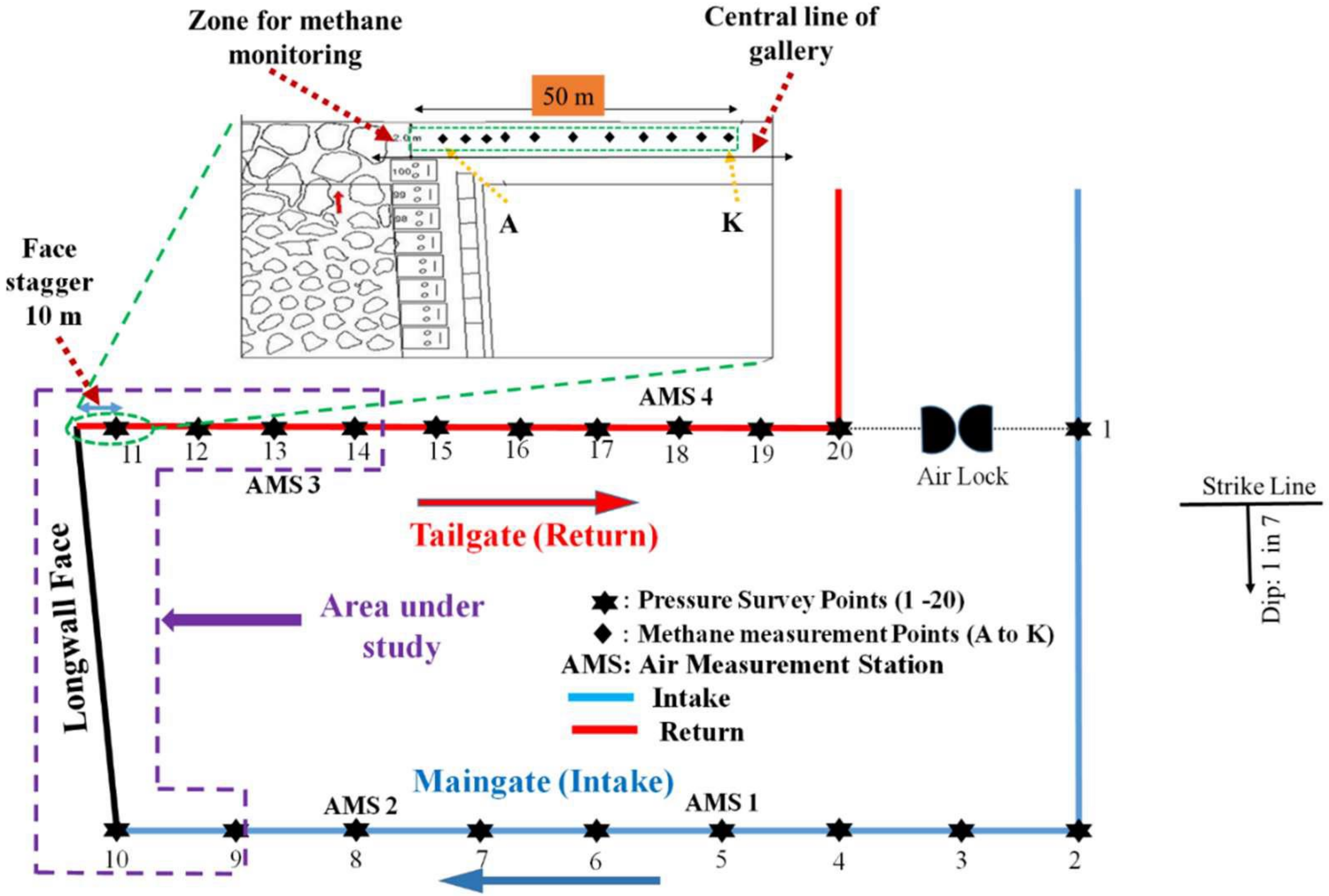


Figure 4.2 Vertical extensions of gas emission space surrounding a longwall gob.

... gas emission space created by longwall



Zone for methane monitoring
Central line of gallery
50 m
2.0 m
A
K
Face stagger 10 m
AMS 4
AMS 3
AMS 2
AMS 1
11
12
13
14
15
16
17
18
19
20
1
10
9
8
7
6
5
4
3
2
Air Lock
Strike Line
Dip: 1 in 7
Tailgate (Return)
Longwall Face
Area under study
: Pressure Survey Points (1 -20)
: Methane measurement Points (A to K)
AMS: Air Measurement Station
Intake
Return
Maingate (Intake)

Fig. 4.2 [2] shows the vertical extent of the gas emission space created by longwall mining and the percentage of gas content released by various coal seams contained in the gas emission space as a function of its distance from the mined coal seam. The vertical dimension of the gas emission space is highly dependent on the width of the longwall face. In general, the wider the longwall face, the greater the vertical dimension of the gas emission space and, consequently, the higher the specific gob methane emission (ft^3 of gas emitted per acre/day). In one study, the specific methane emission increased by 50% when the face width increased from 630 to 700 ft [3]. Very wide (1000 + ft) longwall faces also exacerbate methane and respirable dust concentrations at the tailgate and require a larger quantity of air at the intake end of the face to stay in compliance with statutory requirements.

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/longwall-mining

Estimated Cost for Mildly Gassy Coal Seams (Gas Content Less Than 100 ft^3/ton)

Premining degasification: For coal seams with gas contents less than 100 ft^3/ton, there is generally no need for pre-mining degasification.

Postmining degasification: Two gob wells are recommended for the longwall panel. The first gob well should be installed within 1000 ft of the setup entry and the second one installed in the middle of the panel.

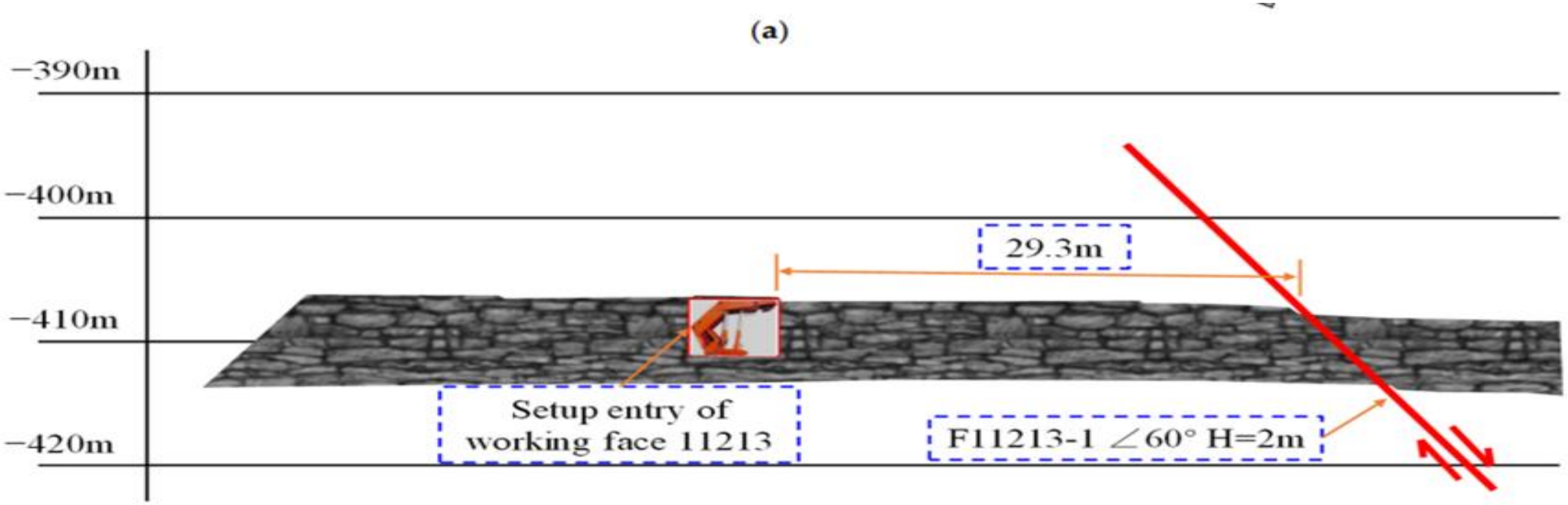


Figure 4. Structure of overlying strata near the setup entry in the longwall panel of working face 11213. (**a**) Rock structure in the inclined direction. (**b**) Fault influence (along the tailentry section).

4.3 Mildly Gassy Coal Seams

A typical layout for a longwall face operating in a mildly gassy coal seam is shown in Fig. 4.3.

4.3.1 Premining Degasification

In coal seams with gas contents less than 100 ft^3/t, there is generally no need for premining degasification. However, it may be desirable to drill the longwall panel horizontally at 1000-foot intervals for exploration and respirable dust control.

4.3.2 Postmining Degasification

At least one gob well within 1000 ft from the setup entry is recommended because longwall gobs always produce some gas. Normally, there exists a very good longitudinal communication over the longwall panels, and a single gob well can have a drainage radius of 3000 to 5000 ft. A second gob well may be needed to cover a 15,000- to 20,000-foot long panel. The gob well diameter can range from 4 to 8 in., and gas production can be enhanced with blowers.

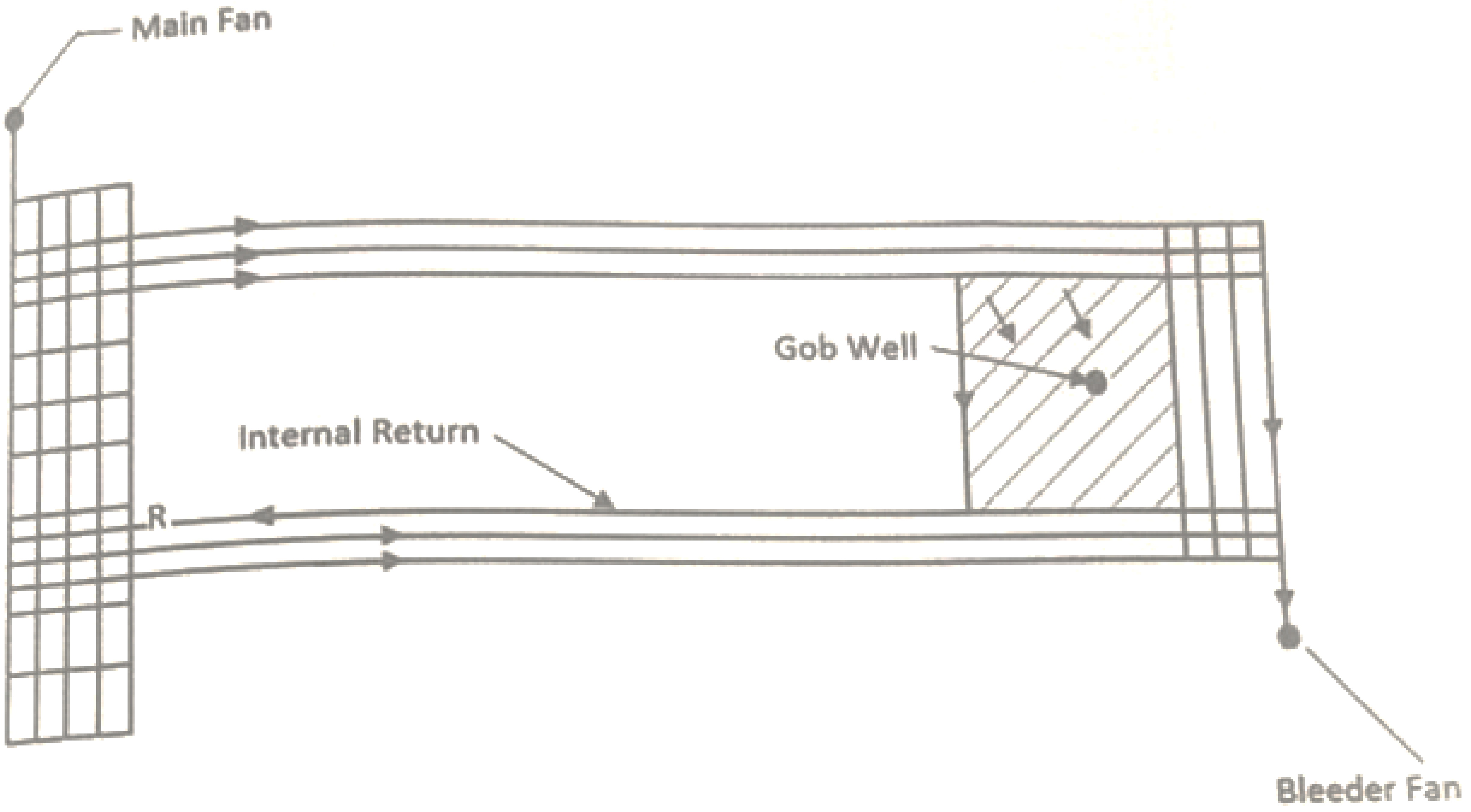


Figure 4.3 Ventilation layout for a longwall panel in mildly gassy coal seams.

Estimated Cost for Moderately Gassy Coal Seams (Gas Content 100–300 ft^3/ton)

Premining degasification: The longwall panel should be drilled horizontally at 1000 ft intervals, and development boreholes should be drilled to degas development sections. Total in-mine drilling footage for a typical panel may total 25,000 ft.

Postmining degasification: In moderately gassy coal seams, a proposed longwall panel may need 5–6 gob wells. The diameter and size of exhaust fans will depend on local conditions.

4.4 Moderately Gassy Coal Seams

A typical layout for a longwall face operating in moderately gassy coal seams is shown in Fig. 4.4.

4.4.1 Premining Degasification

Moderately gassy coal seams generally need to be degassed in advance of mining. Fig. 4.5 shows a degasification scheme with in-mine horizontal boreholes. Boreholes drilled parallel to the development headings degas them, and cross-panel boreholes drilled into the longwall panels degas the longwall panels. If these boreholes are drilled promptly and produced efficiently, nearly 50% of the in situ gas can be drained before mining. The outbye boreholes can be 1000 ft apart, but inbye boreholes should be spaced closer.

4.4.2 Postmining Degasification

A gob well must be installed within 500 ft from the setup entry and, based on local experience, additional gob wells should be installed at 30- to 60-acre spacing. Usually the first gob well is the best producer, but other gob wells also help in controlling methane emissions. With proper planning and blowers on the gob wells to assist in methane drainage, 50 to 60% of total gob methane emissions can be captured. The gob well diameter ranges from 6 to 9 in., and gas production is always assisted with well-designed blowers.

vertical wells typically use 30-60-acre spacing, meaning that the well is assumed to affect the minerals under the 30-60 acres surrounding a well.

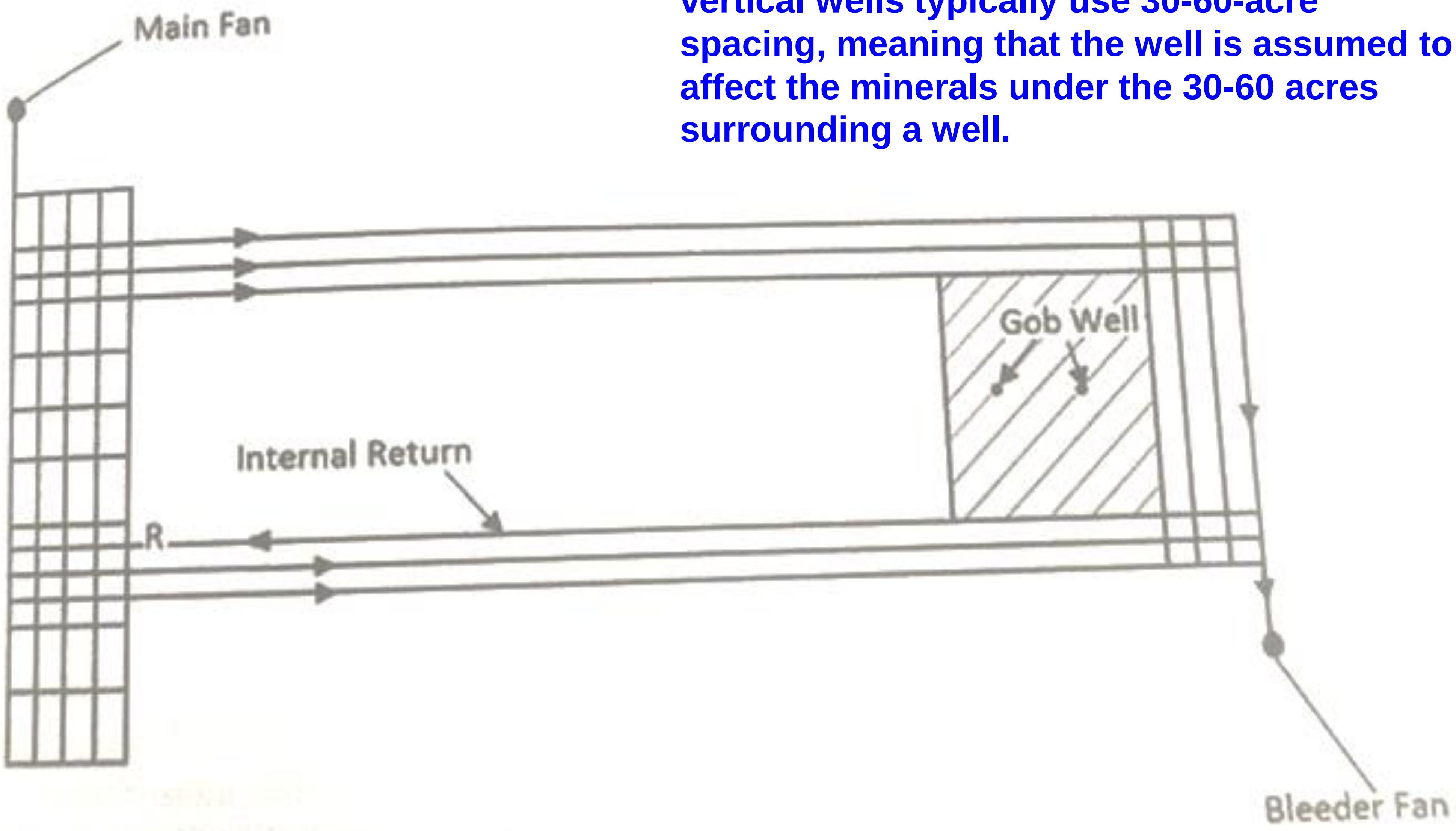


Figure 4.4 Ventilation layout for a longwall panel in moderately gassy coal seams.

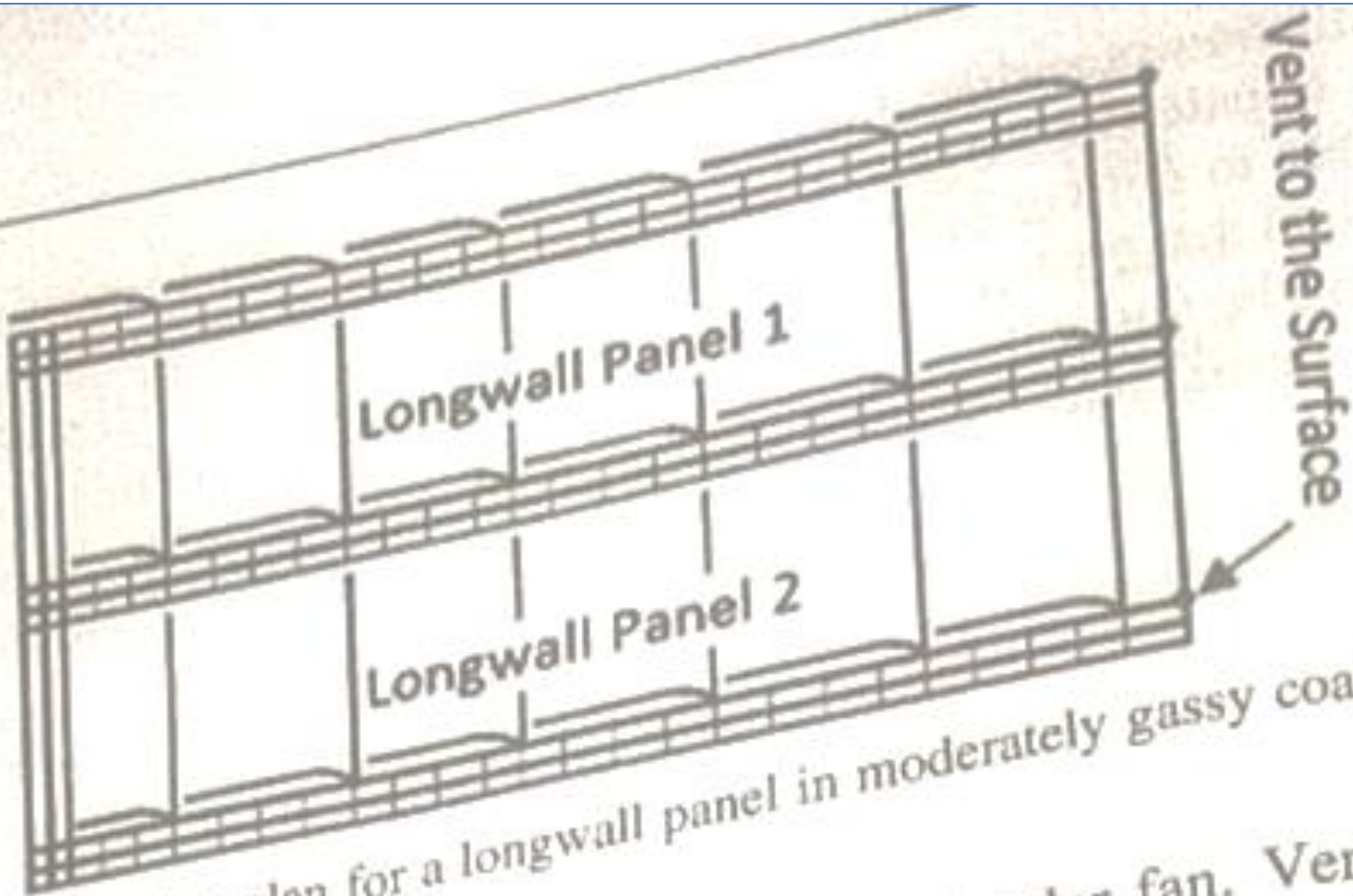


Figure 4.5 Degasification plan for a longwall panel in moderately gassy coal seams.

...ation of a main fan and a bleeder fan. Very high
...ines because all coal seams are liable
...es spontaneous combu...

Estimated Cost for Highly Gassy Coal Seams (Gas Content Over 300 ft^3/ton)

Premining degasification: Highly gassy coal seams must be drained several years ahead of mining with vertical frac wells (wells that have been hydraulically fractured). These frac wells can be placed at about a 20-acre spacing. Frac wells drilled about 5 years ahead of mining can drain nearly 50% of the in situ gas prior to mining, but this may not be sufficient. Additional degasification with in-mine horizontal drilling can raise the gas drained to nearly 70%. Horizontal boreholes are drilled 200–300 ft apart to a depth of 900 ft. Assuming a 200 ft interval, nearly 45,000 ft of horizontal drilling and about 15 vertical frac wells may be needed to properly degas the panel.

Postmining degasification: Because of very high gas emissions from the gob, the first gob well must be installed within 50–100 ft from the setup entry. Subsequent gob wells may be drilled at a 6- to 15-acre spacing, depending on the rate of mining and the gas emission per acre of gob. In the US states of Virginia and Alabama, two states with some highly gassy coal seams, gob wells are generally 9–12 inches in diameter. Powerful exhaust fans capable of a suction of 5–10 inches of mercury are needed to capture up to 80% of gob gas emissions.

- Coal seam degasification is needed for mine safety and high productivity, but in highly gassy mines, it becomes quite expensive. In these mines, the processing and marketing of coal mine methane becomes necessary to defray the cost

  - **Improved safety and reduced injury rate**
  - **Improved recovery of in situ coal reserve**
  - **Improved productivity and reduced cost/ton**

4.5 Very Gassy Coal Seams

A typical layout for a longwall face operating in a very gassy coal seam is shown in Fig. 4.6.

4.5.1 *Premining Degasification*

Very gassy coal seams must be drained several years ahead of mining with vertical frac wells. These frac wells can be put at about 20-acre spacing. They can also drain methane from overlying coal seams and reduce gob emissions. Frac wells drilled about 5 years ahead of mining can drain nearly 50% of gas contained in coal, but this may not be enough to sustain a high rate of extraction. Additional degasification is done with in-mine horizontal drilling to remove nearly 70% of in-place gas before mining as shown in Fig. 4.7. Horizontal boreholes are drilled at 200- to 300-foot intervals and are extended beyond the longwall panels to intersect and degas the next development section.

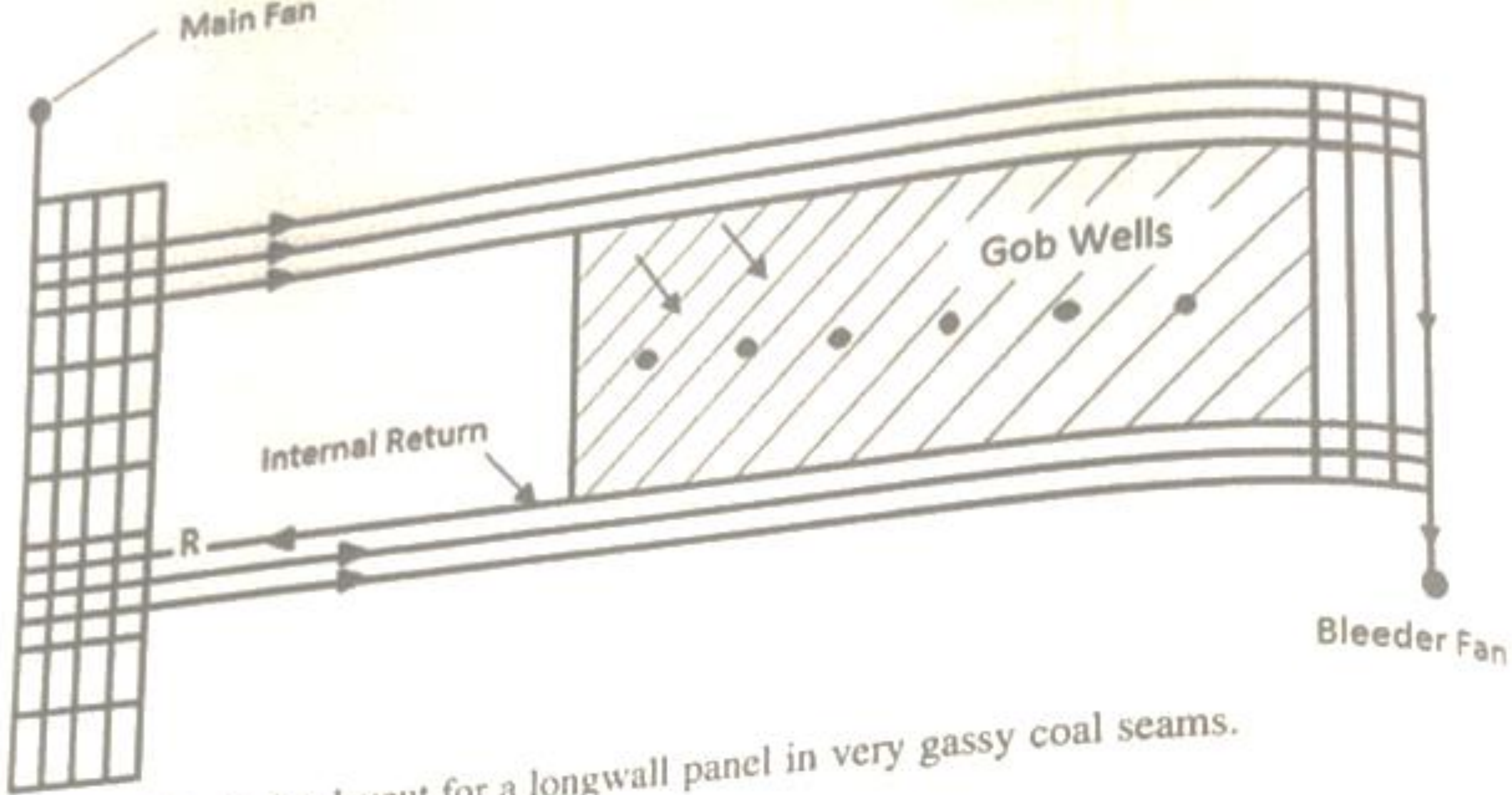


Figure 4.6 Ventilation layout for a longwall panel in very gassy coal seams.

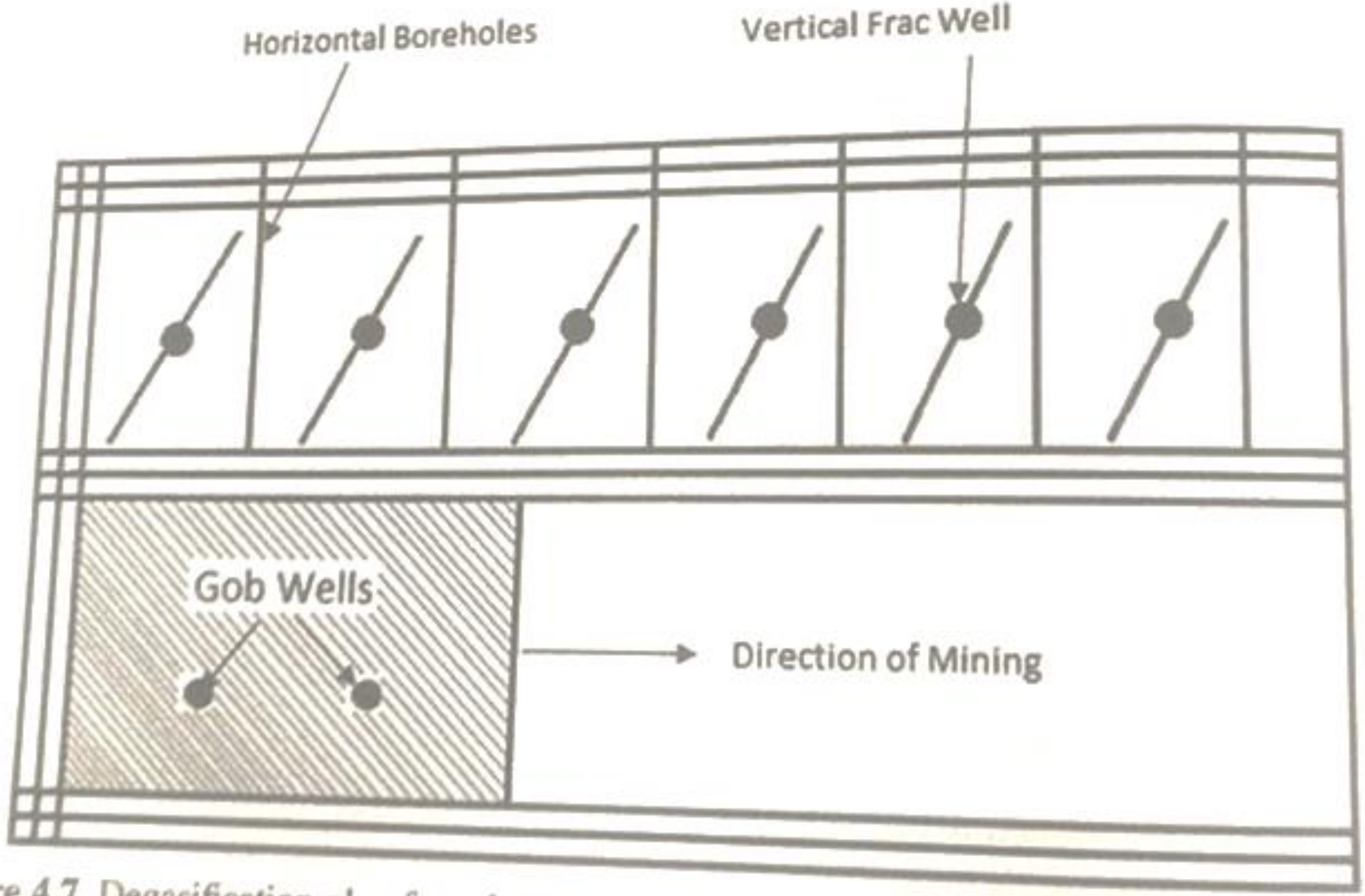


Figure 4.7 Degasification plan for a longwall panel in very gassy coal seams.

4.5.2 Postmining Degasification

Because of very high gas emissions in the gob area, the first gob well must be installed within 50–100 ft from the setup entry. Subsequent gob wells may be drilled at 6–15 acre spacing, depending on the rate of mining and gas emissions experienced. In Virginia and Alabama, the gob wells are generally 9–12 in. in diameter. Powerful blowers with 75–125 Hp motors creating a suction of 5–10 in. of mercury are needed to capture up to 70% of gas emissions.

- **Premining Methane Drainage**
- The area to be mined by longwall mining must be drilled from surface to a depth of 270 ft below the mineable coal seam to confirm the presence of other coal seams/gas-bearing strata.
- Coal cores are carefully collected and gas contents and, sometimes, reservoir pressures are measured. If the gas contents and pressures are high and the coal seams are liable to outburst, they must be adequately degassed prior to mining. Failure to degas the underlying coal seams have resulted in mine disasters in many European and Australian coal mines owing to sudden outburst of gas and coal fines . At present there are two techniques available to pre-drain these coal seams:

✓ **Hydro-fracturing of underlying coal seams by a vertical well and**

✓ **Horizontal boreholes drilled from surface to intersect all underlying coal seams in the gas emission space, with or without hydrofracturing.**

Hydrofracturing of Underlying Coal Seams

Frac wells are drilled from surface in a grid pattern over the longwall panels liable to floor emissions to intersect the underlying coal seams/gas-bearing noncoal strata. High-pressure water (or other fluids, e.g., nitrogen foam) with sand is pumped into these formations to create a vertical fracture that can run several hundred feet on either side of the frac well (Fig. 17.1). The liquid is pumped out, but sand remains in the fracture and keeps it open for gas to escape to surface. Several coal seams/gas-bearing horizons can be fracked from a single well.

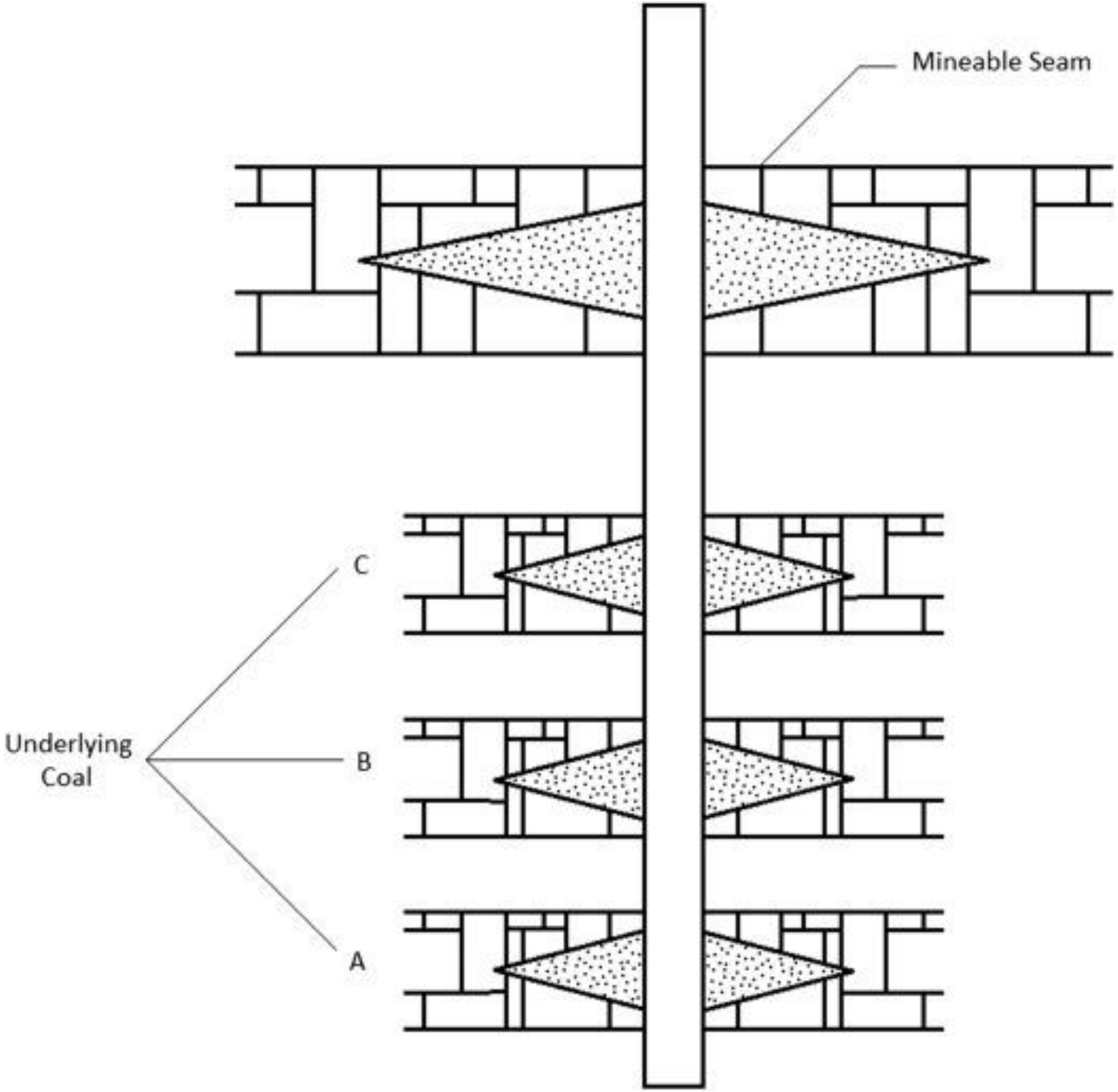
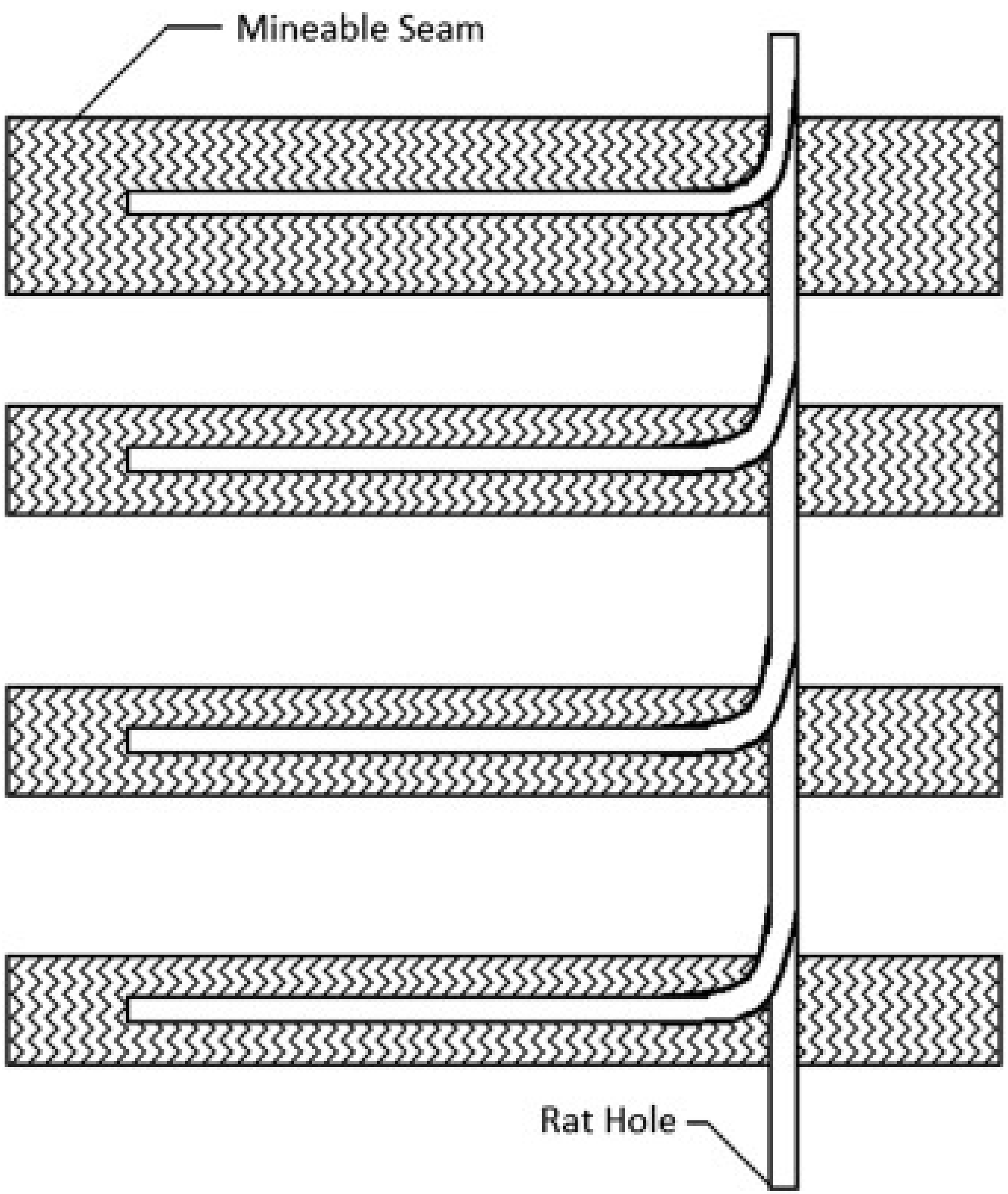


Figure 17.1. Vertical well with multiple seam completion.

Under ideal conditions, 60%–70% of the gas in the coal seams can be removed by vertical wells if drilled and produced for 5–10 years in advance of mining. Reservoir pressures can be reduced by 80% prior to mining. This technique is ideally suited to deep, very gassy coal seams with low to medium permeability (1–10 md). Its effectiveness may be reduced if the coal seam is deeper than 4000 ft where the coal seam permeability is generally less than one microdarcy.

Horizontal Boreholes Drilled from Surface

It is a relatively new technique where a vertical well is drilled from surface, but it is deviated by 90 degrees to make it horizontal and intersect a number of coal seams that needs to be degassed. Fig. 17.2 shows the general layout of a typical drilling scheme.



RAT HOLE

- a shallow hole drilled near a well to accommodate the drill string joint when not in use.
- a small hole drilled at the bottom of a larger hole.

Figure 17.2. Horizontal boreholes in multiple seams drilled from surface.

- The horizontal extension can be 3000–10,000 ft, depending on the depth of the coal seam and the type of drill rig used. The borehole can be lined with slotted liners to guard against accidental closure due to ground movement.
- Gas production even prior to mining could be quite brisk if the coal seams are less than 2000 ft deep and have medium to high permeability.
- Gas production can be enhanced by installing an exhausting fan with a negative pressure of 3–5 psi. These boreholes provide a bypass for floor gases, and thus, gas emission on longwall floors is minimized.

15.2.2 Gas Production From Horizontal and Vertical Wells

The initial time-dependent flow, steady-state flow, and eventual production decline from vertical and horizontal wells have been discussed in details by Thakur [1]. Only steady-state flow will be discussed here.

15.2.2.1 Production From Horizontal Boreholes

The most reliable production estimation for horizontal boreholes/wells is done by the "specific gas production" rates as defined earlier. The data for some important coal seams are presented in Table 15.2.

Table 15.2 Specific Gas Emissions for Coal Seams

Coal Seam	Depth (ft)	Rank	Specific Gas Production (MCFD/100 ft)
Pittsburgh	500-1000	High Vol. Bituminous	15.00
Pocahontas No. 3	1400–2000	Low Vol. Bituminous	8.00
Blue Creek/Mary Lee	1400–2000	Low Vol. Bituminous	9.00
Pocahontas No. 4	800–1200	Medium Vol. Bituminous	5.00
Sunnyside	1400–2000	High Vol. Bituminous	9.00

MCF: Thousand cubic feet
MCFD: Thousand cubic feet per day

The specific production goes down with time and is about 3–4 MCFD/100 ft at the time of plugging just prior to mining through the wells.

Thakur [1] also derived mathematical expressions for gas flow from horizontal boreholes. It is given by Eq. (15.2).

$$Q = At^{n} \tag{15.2}$$

where Q is the cumulative production in MCF; A is the initial production in MCFD (months); t is the time in day (months); n is a characteristic of the coal seam.

Eq. (15.2) can also be written as follows:

$$\ln Q = \ln A + n \ln t \tag{15.3}$$

A plot of ln Q against ln t yields a straight line. The characteristic "n" varies from 0.8 to 1.00.

15.2.2.2 Gas Production From Vertical Wells

Production from a vertical well can be estimated by Eq. (15.2) but another estimate is provided by Eq. (15.4).

$$q = \frac{707.8\,kh\left(p_e^2 - p_w^2\right)}{\bar{\mu}\,\bar{z}\,T\ln(r_e/r_w)} \tag{15.4}$$

Where q = cubic ft/day at 60°F and 14.67 psia; k = permeability in darcy; h = thickness in ft; p_e = pressure at external radius, r_e; p_w = pressure at the well radius, r_w; $\bar{\mu}$ = average viscosity; $\bar{z}$ = average compressibility factor; T = temperature in degree Rankine (Fahrenheit + 460).

For liquid flow, Eq. (15.4) becomes:

$$Q = \frac{0.03976\,kh\,(p_e - p_w)}{\mu \ln(r_e/r_w)} \tag{15.5}$$

where Q is in CF/day and μ is liquid viscosity.

For example,

Calculate gas and water flow from a well producing steadily under the following conditions:

$k = 0.003$ darcy (3 md)
$h = 40$ ft
$\mu = 0.02$ cp
$z = 0.90$
$T = 60°F$ (+460)
$r_e = 1000$ ft
$r_w = 0.25$ ft
$p_e = 500$ psi
$p_w = 50$ psi

Using Eq. (15.4),

$$Q = \frac{707.8 \times (0.003)40(500^2 - 50^2)}{0.9 \times 520 \times (0.02) \times \ln\left(\frac{1,000}{0.25}\right)}$$

$$= 270.9 \text{ MCFD}$$

The above conditions describe a typical well drilled into a thick seam with good permeability. The well is produced at a constant pressure of 50 psi. Similarly, using Eq. (15.5), the water flow can be calculated as 46.2 bbl/day.

a) Calculate the steady-state gas production from a vertical well for the following given conditions:

- Permeability of coal = 3 md
- Thickness of the coal seam = 40 ft
- Average viscosity of gas = 0.02 cp
- Average compressibility factor = 0.90
- Temperature = 60 °F
- The radius of the well = 0.25 ft
- External radius = 1000 ft
- Pressure at external radius = 500 psi
- Pressure at the well radius = 50 psi.
- Coal density = 0.04 ton/ft^3

If the gas content of coal is 600 ft^3/ton, how many fracture wells will be needed to degas a longwall panel of 1000 ft × 10,000 ft in 5 years? Assume that the total gas production declines by the following power law with the characteristic 'n' of the coal seam equal to 0.8:

$Q = At^n$, where *Q* is the cumulative gas production, *A* is the initial production, *t* is the time in day.

Calculate gas and water flow from a well producing steadily under the following conditions:

$k = 0.003$ darcy (3 md)
$h = 40$ ft
$\mu = 0.02$ cp
$z = 0.90$
$T = 60°F\ (+460)$
$r_e = 1000$ ft
$r_w = 0.25$ ft
$p_e = 500$ psi
$p_w = 50$ psi

Using Eq. (15.4),

$$Q = \frac{707.8 \times (0.003) 40 (500^2 - 50^2)}{0.9 \times 520 \times (0.02) \times \ln\left(\frac{1,000}{0.25}\right)}$$

$$= 270.9 \text{ MCFD}$$

Cumulative gas production = $270900 \times (365*5)^{0.8}$ = 110,108,108 ft^3
Number of wells = (1000*10000*40*0.04*600)/(110,108,108)= 87

15.3 Application of In-Mine Horizontal Drilling

First application of this technique was reported by Thakur [3,4] in 1978. A 1200 ft long borehole was drilled ahead of a development section from the return side of the section as shown in Fig. 15.7. It produced about 500 MCFD of methane.

The borehole was connected to a vertical borehole with pipes, and gas was safely discharged on surface. The impact of degasification was noted as follows:

1. The greatest impact of degasification was in the face area where methane concentration dropped to 0.25% in course of two to 3 months from an initial value of 0.95%.
2. The methane concentration in the section return (at the last open crosscut) fell to 50% of its original value indicating a methane capture ratio of 50%.
3. The immediate influence of those boreholes was felt up to a radius of 400 ft. This indicated that only one borehole drilled in the outermost airway of a section can adequately degas the

section if the width of the development section did not exceed 400 ft and the coal seam had good permeability.

Application of in-mine horizontal drilling for simultaneous degasification of the development headings and the longwall panel is shown in Fig. 15.8 [5].

In moderately gassy coal seams, the drilling is done at 1000 ft intervals for adequate degasification of the longwall panel. For highly gassy coal seams the first phase of degasification is done by vertical drilling and hydrofracturing as described in the next sections. The supplementary horizontal boreholes are drilled at closer intervals of 100–200 ft to remove 50%–70% in situ gas prior to mining.

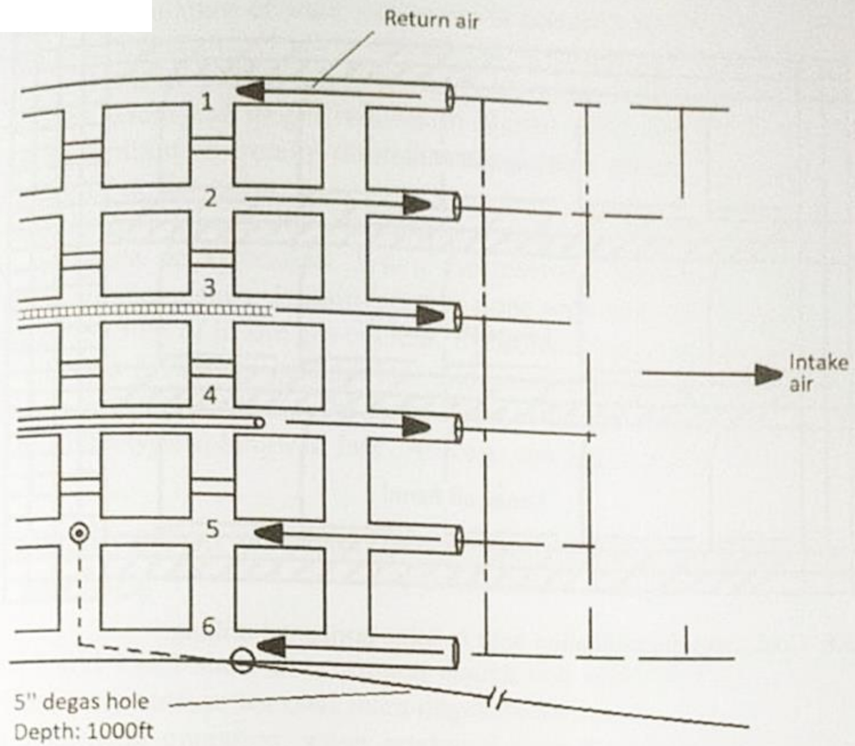


Figure 15.7 Layout of a development section with a long degas hole.

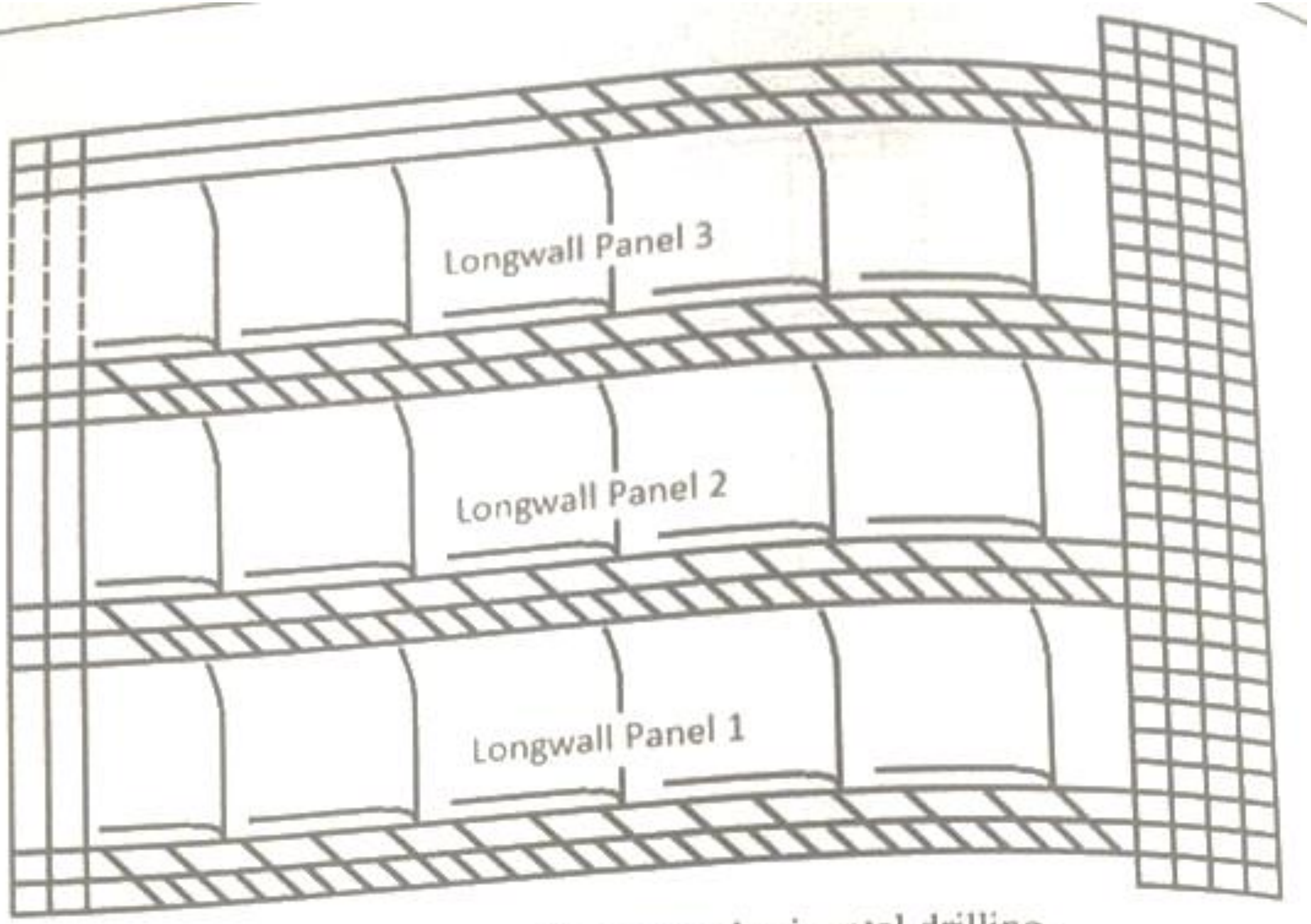


Figure 15.8 Coal seam degasification with in-mine horizontal drilling.

15.4 Application of Vertical Wells With Hydraulic Fracturing

This is currently the most popular method of coal bed gas production, but it is also used for degasification of deeper coal seams (deeper than 1500 ft) where in-mine horizontal drilling is not enough. Deeper coal seams with gas contents of 300–700 ft^3/t must be drilled vertically, and the coal seams should be hydraulically fractured to drain about 50% of the gas in situ.

Fig. 15.9 shows the vertical section of a typical well. Details of well completion are given by Thakur [1] elsewhere.

In summary, a mixture of sand and water is pumped into the coal formation at 30 bbl/min or a higher rate (1 bbl = 42 gallons). It creates a vertical fracture in coal seams that is 1000 to 2000 ft long, ½ to ¾ in. wide, and about 20 ft high at the well bore. The width and height reduces to almost nil at the tip of the fracture at 1000 ft or so. Drilling is usually done three to 5 years ahead of mining to achieve 50% drainage of in situ gases.

A typical longwall face 1000′ × 15,000′ in area may need 10 to 12 vertical frac wells for adequate degasification. When the reservoir pressure is reduced to less than 200 psi, supplementary degasification is done with horizontal drilling to remove additional 25%–30% of in situ gas content. Hydrofracking is typically done with plain water or nitrogen foam, but gelled water and cross-linked gels have been also used depending on the specifics of the coal seam. Refer to Chapter 4, Figure 4.7 for the layout of frac wells on a typical longwall face. Average spacing is at 20–25 acres per well.

1 gallon = 3.8 L

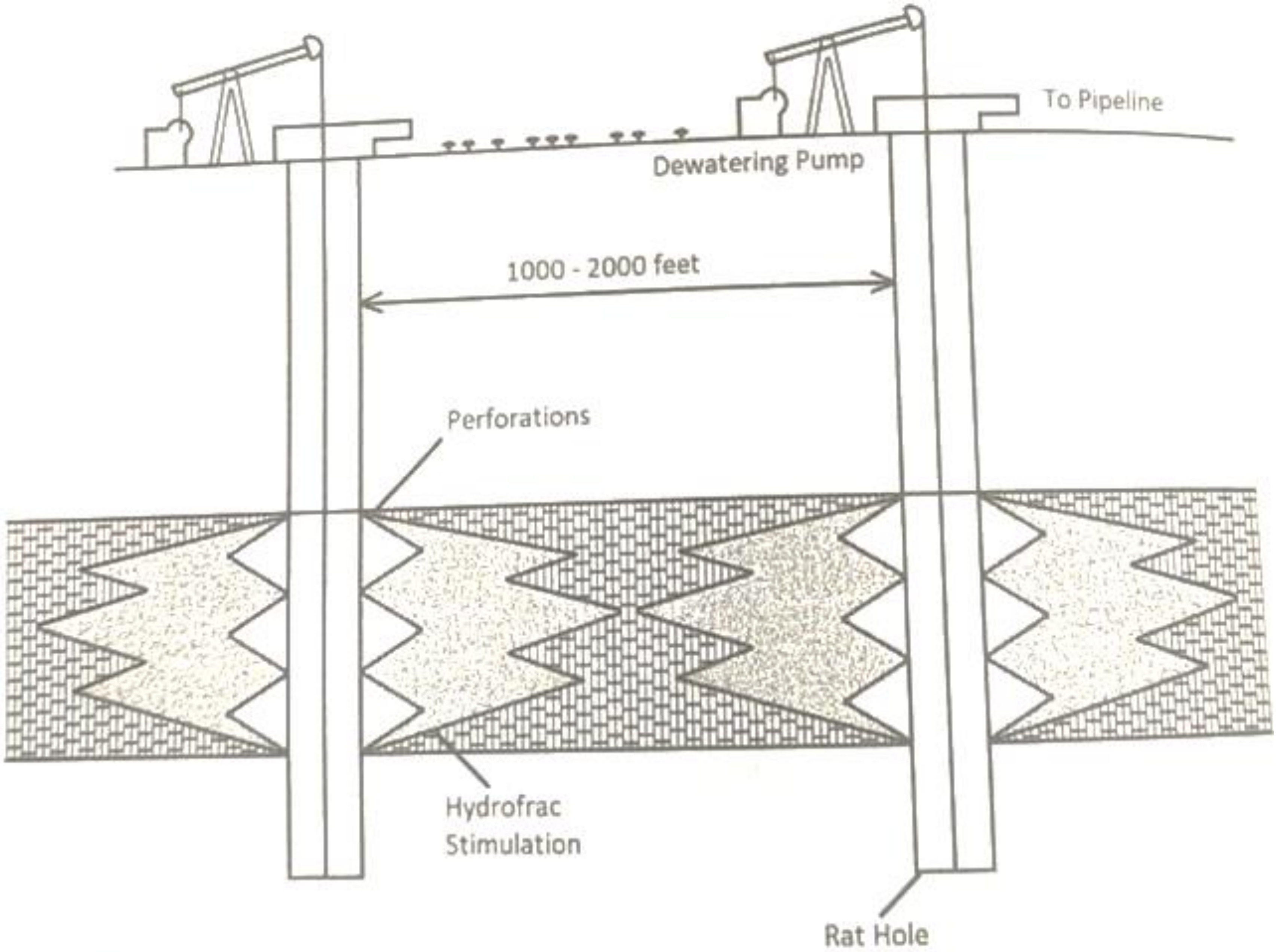


Figure 15.9 Vertical hydrofracked wells.

RAT HOLE

- a shallow hole drilled near a well to accommodate the drill string joint when not in use.
- a small hole drilled at the bottom of a larger hole.

15.5 Application of Horizontal Boreholes Drilled From Surface

Figs. 15.10 and 15.11 show the common design and application of horizontal boreholes drilled from surface for coal seam degasification.

For a successful operation, water produced from the horizontal laterals must be removed. A production well with a sump (drilled below the coal seam to be degassed) is first drilled. Nearly 300 ft away, a vertical (access) well is drilled (Fig. 15.10). When it approaches the target coal seam, it is deviated by 90 degrees to intersect the coal seam horizontally passing through the production well.

The borehole can be laterally extended to 3000 to 5000 ft depending on the depth of the coal seam. A water pump is installed in the production well to remove water and coal fines, and gas production is maintained. Very expensive drill rigs and instruments are needed to articulate a horizontal borehole assembly to stay in a thin coal seam and reach a depth of 3000 to 5000 ft. The cost of drilling horizontal boreholes from surface is, therefore, much higher ($100/ft) than the cost of drilling in-mine horizontal boreholes (usually less than $20/ft). The degree of degasification achieved is the same, about 50% of gases in situ.

Premining degasification of all moderately and highly gassy coal seams is highly recommended. Besides making mining safer, it improves coal productivity significantly cutting down the cost of mining. In one very gassy mine, the coal productivity jumped from 14 tons/man-day to 40 tons/man-day after about 70% of in situ gas was drained. The produced gas can be processed to meet the pipeline gas specifics and marketed to defray the cost of degasification [6].

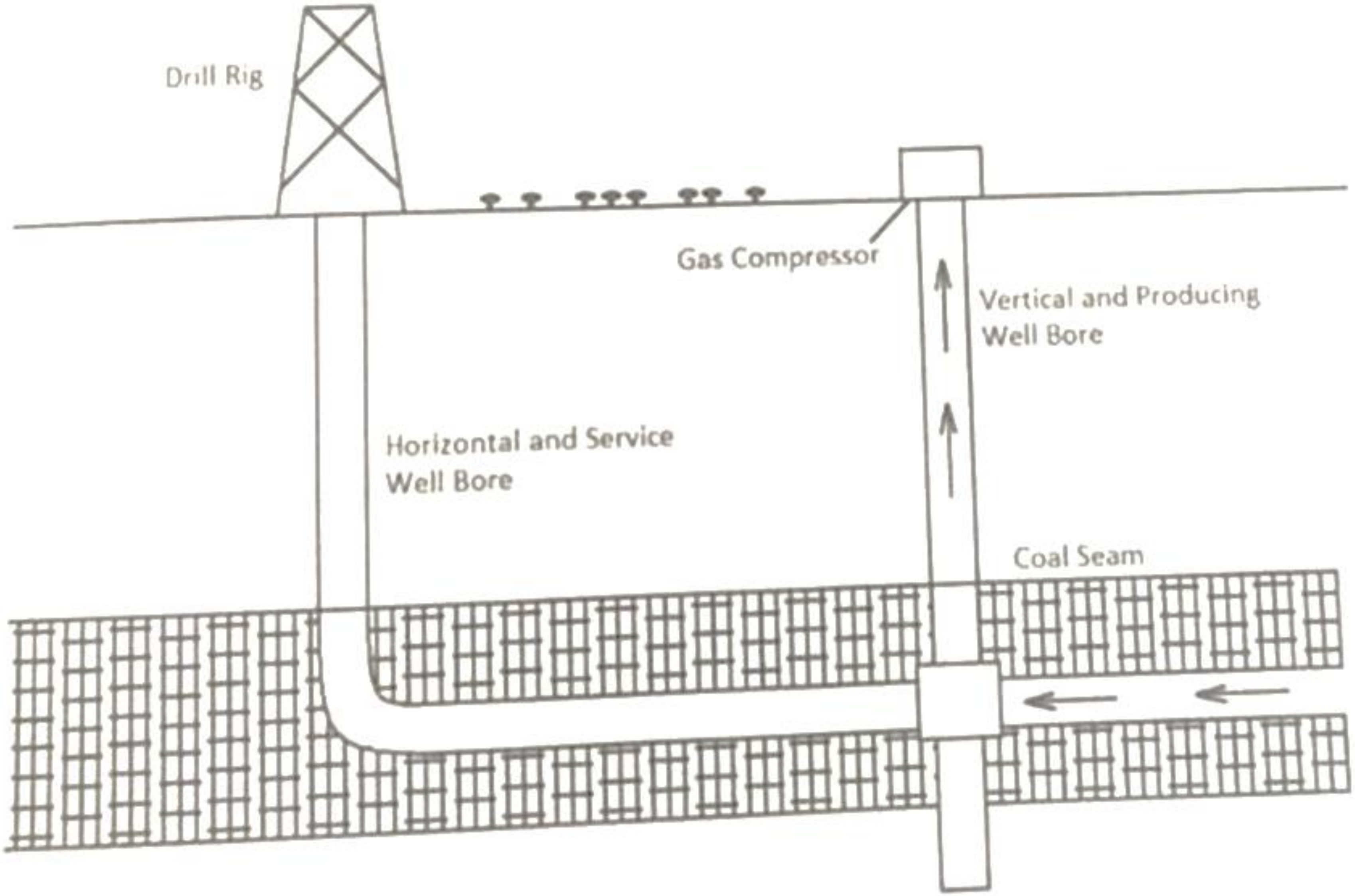


Figure 15.10 Horizontal boreholes drilled from the surface.

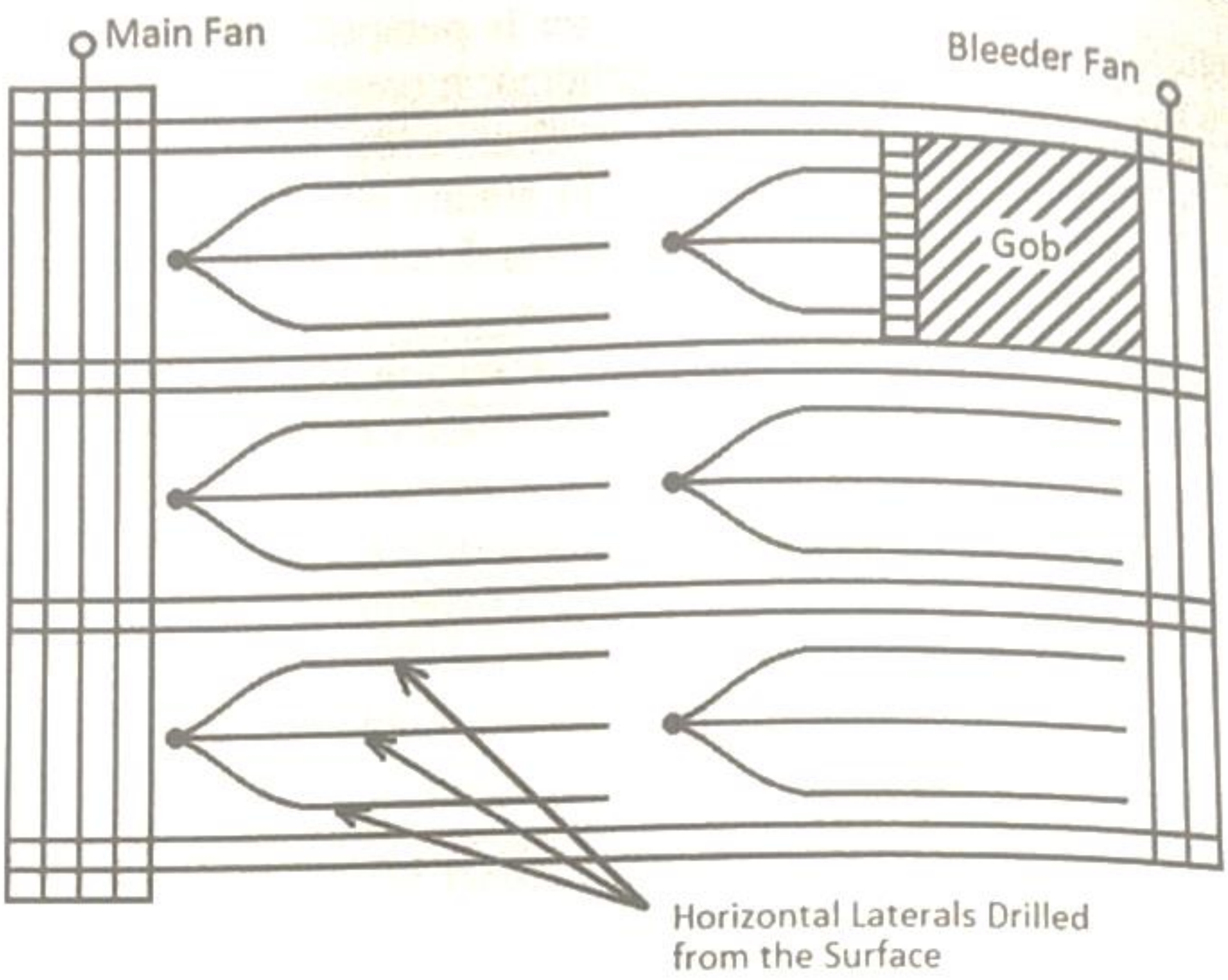


Figure 15.11 Coal seam degasification with horizontal boreholes drilled from the surface.

15.6.1 *Estimation of Total Methane Emissions at the Longwall Tailgate by Direct Measurements*

An estimate of methane emissions at the tail end of a longwall face can be derived by the following equation:

$$Q = Qo + V(A - B) - C(X) \tag{15.6}$$

where Q = total methane emissions at the tail end of a longwall face, ft^3/min; Qo = total methane emissions when no mining is being done, ft^3/min; V = the rate of mining in tons/min; A and B are the gas contents of coal prior to mining and after mining respectively; C(X) is the methane lost in the gob with air leakage.

An example:

In a properly degassed, moderately gassy coal seam, the following data were measured.

Qo = 100 CFM
V = 8 t/min
A = 120 ft^3/ton; B = 40 ft^3/ton
C(X) = averaged for the entire face at 250 CFM (50,000 CFM lost in gob containing an average of 0.5% methane).

Hence,

$$Q = 100 + 8(120-40)-250$$
$$= 490 \text{ CFM.}$$

To dilute it to 1%, the ventilation air should be 49,000 CFM with a gas layering index greater than five.

15.6.2 Mathematical Derivation of Limiting Methane Concentration at the Tailgate

Assuming that q is the net methane emission ([emission from solid coal + emissions from broken coal] minus methane lost with leak-off air) in a differential element, dx, the mathematical equation for methane concentration is (refer to Chapter 3) given by Equation (15.7). u is the ventilation rate, ft^3/min.

$$\frac{\partial^2 c}{\partial x^2} + u\frac{\partial c}{\partial x} - q = 0 \tag{15.7}$$

The boundary conditions are as follows:

$$\frac{\partial c}{\partial x} = 0 \text{ at } x = 0 \quad \text{(methane concentration is constant)}$$

$$\varepsilon_x \frac{\partial c}{\partial x}\bigg|_{x=L} + uc|_{x=L} = qL \quad \text{(from mass conservation)}$$

The solution of Eq. (15.7) is as follows:

$$c(x) = \frac{q}{u}\left[x - \frac{\varepsilon_x}{u}\left(1 - e^{-ux/\varepsilon_x}\right)\right] \tag{15.8}$$

At $x = L$,

$$C_L = \frac{q}{u}\left[L - \frac{\varepsilon_x}{u}\left(1 - e^{-uL/\varepsilon_x}\right)\right] \tag{15.9}$$

If L is large, we can discard e^{-uL/ε_x} term as zero, and

$$C_L = \frac{qL}{u}\left(L - \frac{\varepsilon_x}{u}\right) \tag{15.10}$$

Thus, the limiting value of C_L is $\frac{qL}{u}$.

An example:

Assume $L = 1000$ ft, $q = 0.3$ ft^3/ft-min

$C_L = 0.8\%$ (or 0.008).

Hence, $0.008 = \frac{0.3 \times 1{,}000}{u}$

or $u = 37{,}500$ CFM.

A check of gas layering index should be made to make sure it exceeds 5.00 (refer to Chapter 4).

a) The following data were measured in a gassy coal seam:

- Total methane emissions when no mining is done = 100 ft^3/min
- The rate of mining = 8 ton/min
- The gas contents of coal prior to mining = 120 ft^3/ton
- The gas contents of coal after mining = 60 ft^3/ton
- The average methane lost in the gob with air leakage in a 1000 ft long face = 200 ft^3/min

Calculate total methane emission at the tailgate. Also calculate the ventilation rate needed to dilute the total methane emission to 0.8%.

Q = 100+8*(120-60)-200 = 140 CFM

Ventilation rate = 40/0.008 = 5,000 CFM

COMPLETION METHODS

- Completion is the process of making a well ready for production (or injection).

- Before selecting a completion method for a CBM well, nine factors should be considered. These are: investment required; number of coal seams encountered by the borehole; expected production rate; reserves in the various coal intervals; coal seam permeability and gas content; type of stimulation treatment expected; wellbore stability problems; future work over requirements; and artificial lift requirements.

- Well completion design should be coordinated with the stimulation strategy. The type of pumping equipment must be considered.
- Besides efficiently removing liquids from the borehole, pump selection should recognize the effects of coal fines and fracturing sand that may migrate back to the wellbore. The estimation of gas production rates expected after stimulation is also important. In most coal bed reservoirs, early flow rates are small. However, flow rates increase with time, as gas desorbs from the coal.
- The tubing in the well must be designed to maximize the lifting of liquids early in the life of the well, to help dewater the coal.

- To help decide the zones to complete, a reserve analysis should be performed on each potential interval to determine the commercial value of the well. The effect of various sizes of stimulation treatments, type of artificial lift, and the size of the tubular have to be determined on the basis of reserves and the expected commercial value.

- Other factors, such as surface injection pressures for the different wellbore configurations and the volumes of fluids required for stimulation, must be estimated.
- The choice of completion type can be made on the basis of the above factors. After the completion type has been chosen, the number of completions within the wellbore is determined, and the final tubing and casing configurations are designed. The different completion methods that are used in CBM are described below.

Artificial lift refers to the mechanical lifting of wellbore fluids to the surface. Mechanical lifting of wellbore fluids is required when reservoir pressure is insufficient to drive reservoir fluids to the surface.

Drilling and Completion Technique Selection for Coalbed Methane Wells

- Many different completion techniques, such as vertical-well multi seam completions and multiple lateral wellbores drilled into a single coal seam, have been used to develop coalbed methane (CBM) reservoirs.
- Stimulation techniques include openhole underream, cavity creation, and hydraulic fracturing.

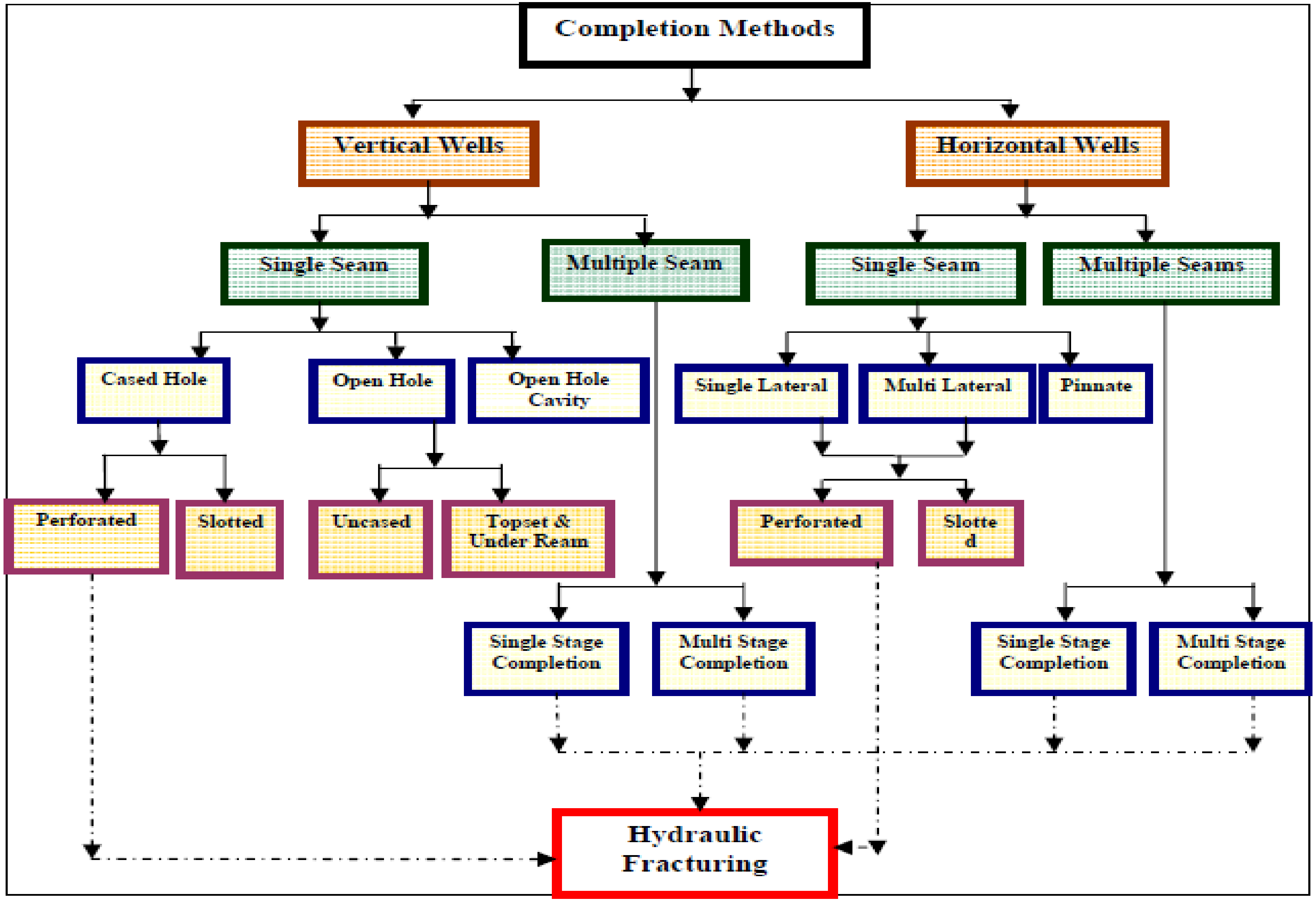


Figure : Drilling and completion methods for CBM reservoirs

Liner Completion

- Barefoot completions normally target hard, consolidated reservoir rocks. Wells in reservoirs that are susceptible to sand production will require different well completions. For wells requiring sand control, we can use ***Open-Hole Slotted Liner Completions***, ***Open-Hole Screen Completions***, or most commonly, ***Gravel Pack Completions***.

- A liner is a casing string that does not go to the surface. A typical ***Cemented Liner Completion*** is shown in **Figure 7.09 (A)**. This particular completion does not offer any sand control capability but is included here to introduce the concept of a liner. As we can see from this figure, the liner does not go to the surface but is hung from a ***Liner Hanger***. The cemented liner completion has many of the advantages of a ***Cased and Perforated Completion*** but at a reduced cost. Because the liner in this completion is cemented in-place, (1) it does not represent an open-hole completion and (2) it requires perforations for the well to access the reservoir.

casing string: An assembled length of steel pipe configured to suit a specific wellbore

Figure 7.09 (A). Example of a Cemented Liner Completion without Tubing

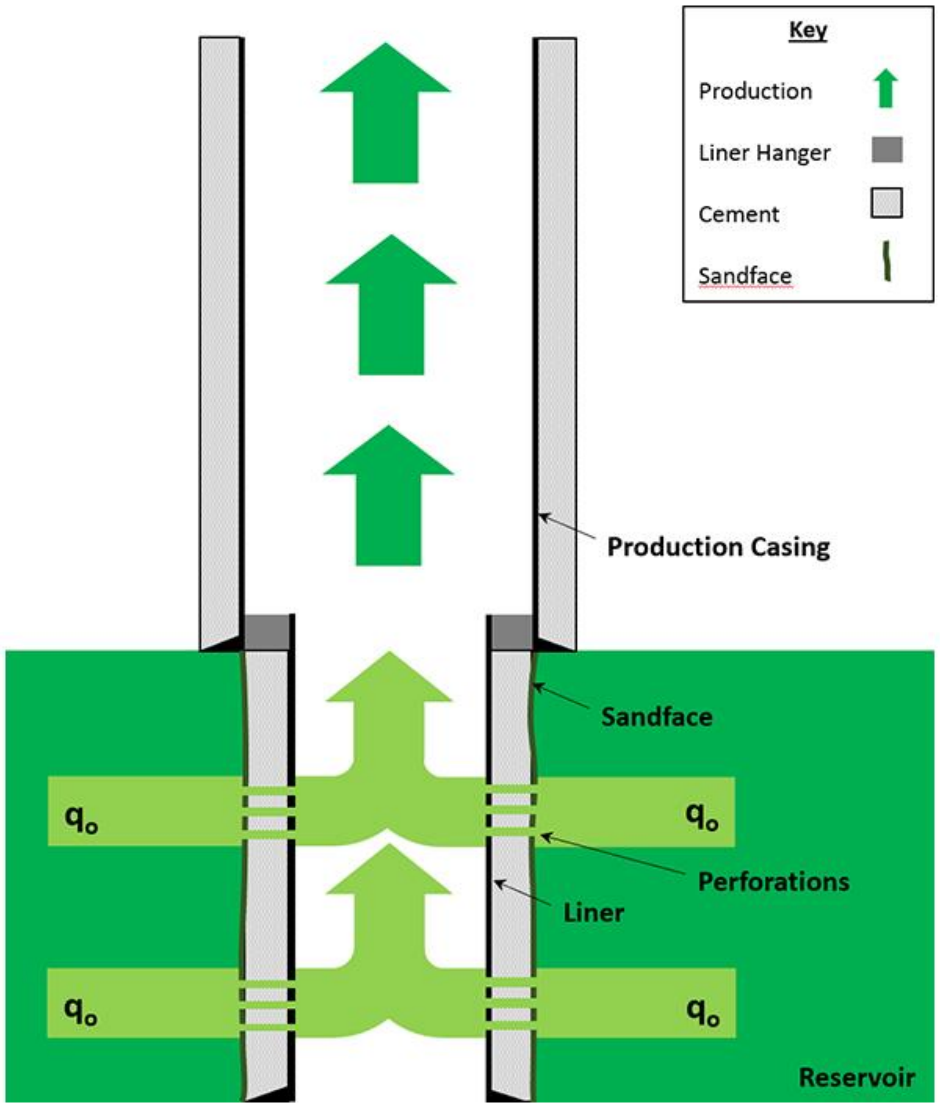
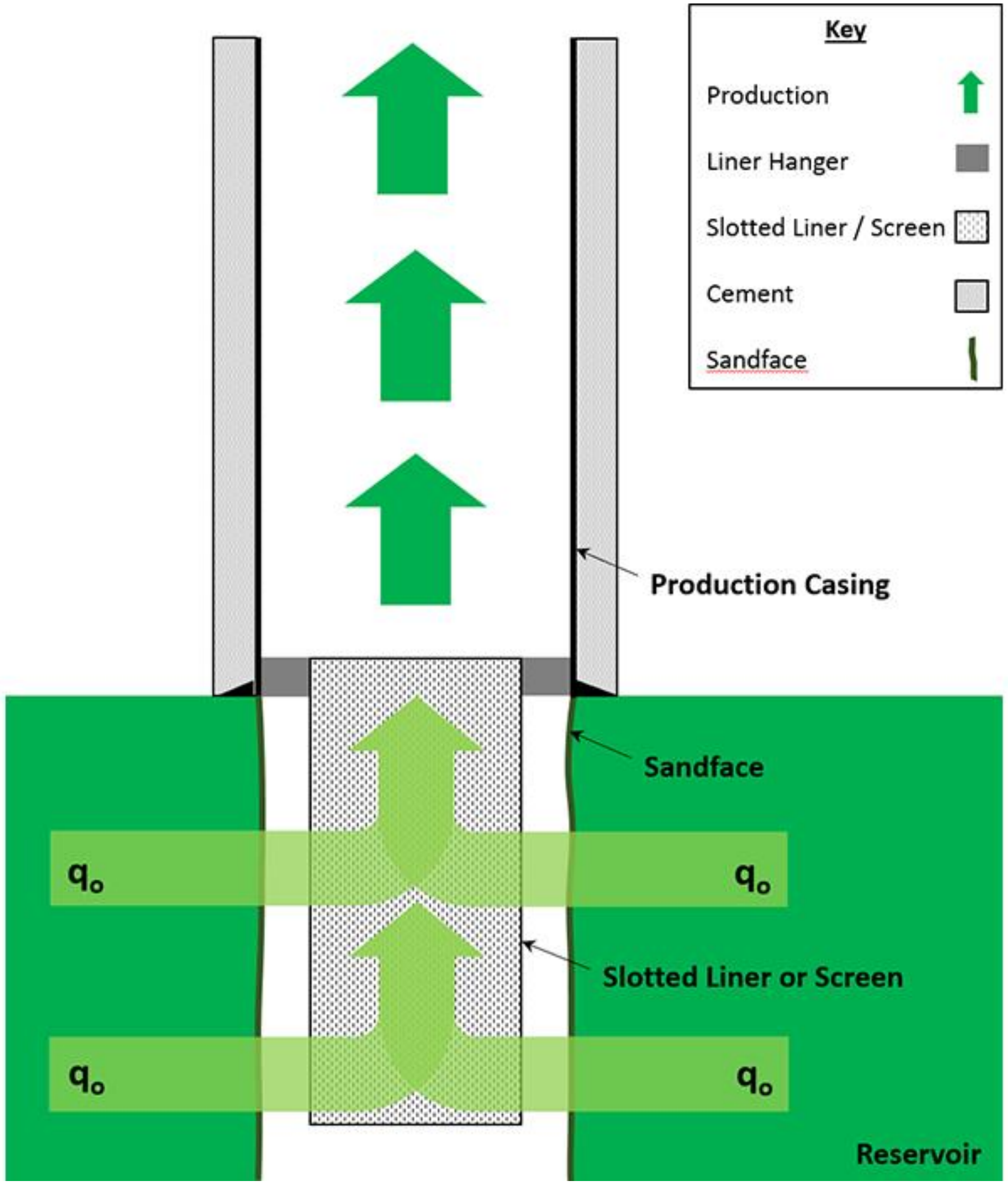


Figure 7.09 (B). Example of either Open-Hole Slotted Liner or Screen Completion without Tubing



- The other completion in **Figure 7.09 (B)** either the ***Slotted Liner Completion*** or the ***Screen Completion***, is an open-hole completion and does offer some sand control capability. Note that we have not cemented the slotted liner or screen set across the reservoir, so these are open-hole completions, but not barefoot completions.
- A slotted liner is a liner with pre-milled slots, while a screen is a liner with pre-milled holes. These liners do not require perforations to achieve access to the reservoir. **Figure 7.10** provides a more detailed illustration of these liner types.

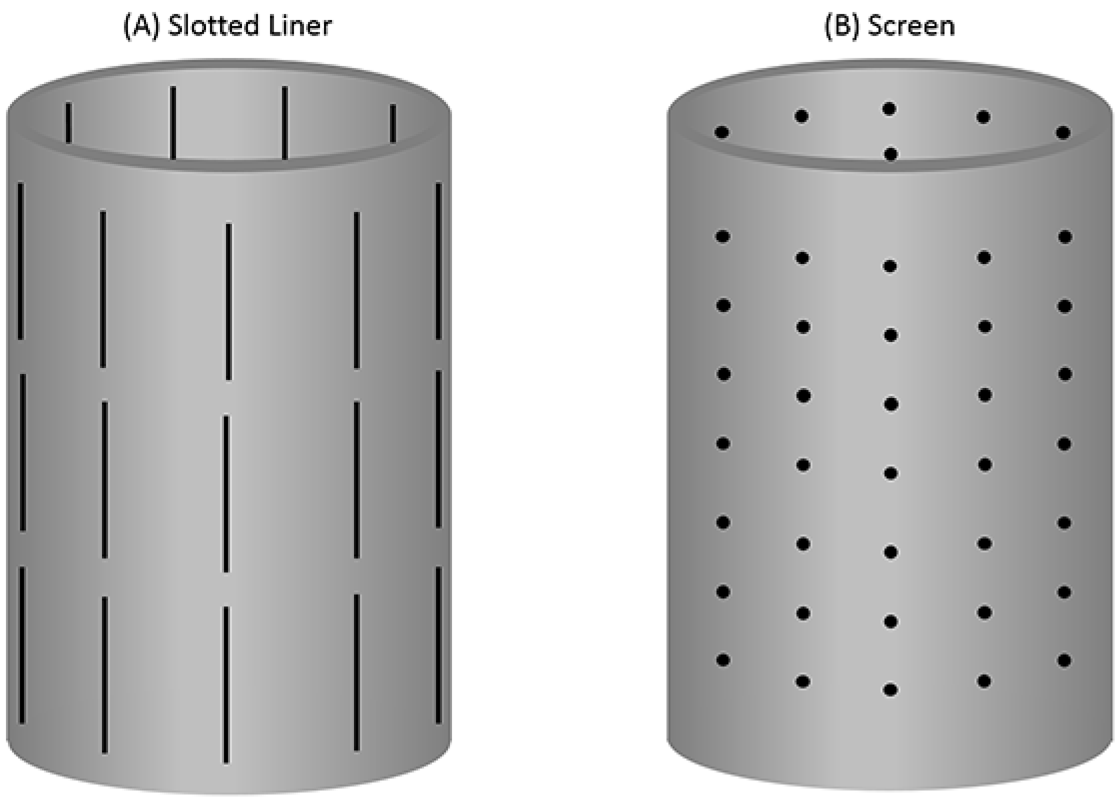


Figure 7.10: Slotted Liner and Screen

- There are many applications for slotted liners and screens and they provide partial sand control with the physical dimensions of the openings acting as filters against the sand production. This sand control, however, is limited because the openings may eventually plug, causing a reduction in the oil rate.

- The most common method of sand control is with gravel pack completions. Two examples of gravel pack completions, one cased and perforated completion and one open-hole completion, are shown in **Figure 7.11**. In these completions, gravel is placed either between a slotted liner (or screen) and the casing (or sandface) to act as a filter for the formation sand.
- The gravel is selected to have good permeability so as not to create a significant pressure drop through the gravel pack and to have good filtering capability. This gravel is often treated with resin to improve its filtering capability.
- There are many variants to the gravel pack, such as pre-packed liners or screens (two concentric slotted liners or screens with gravel pre-packed between them) or frac-pack (combination of hydraulic fracturing and gravel packing

Figure 7.11a: Example of a Cased and Perforated Gravel Pack Completion without Tubing

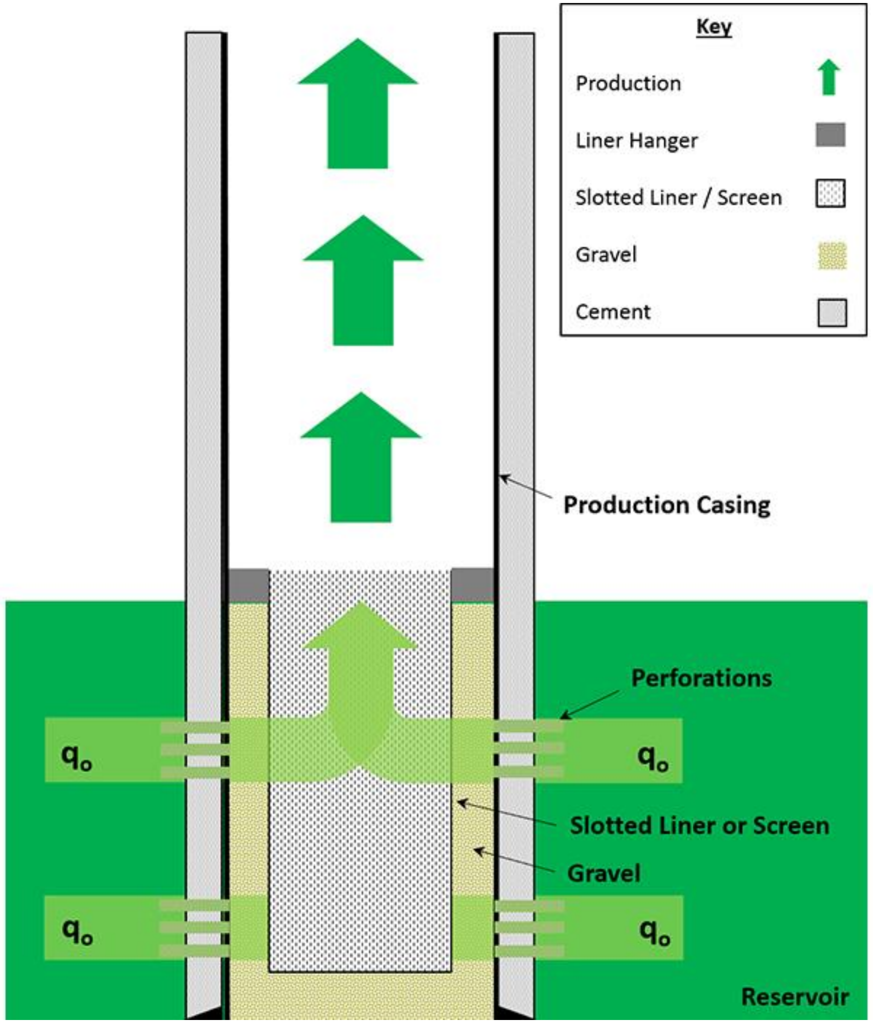
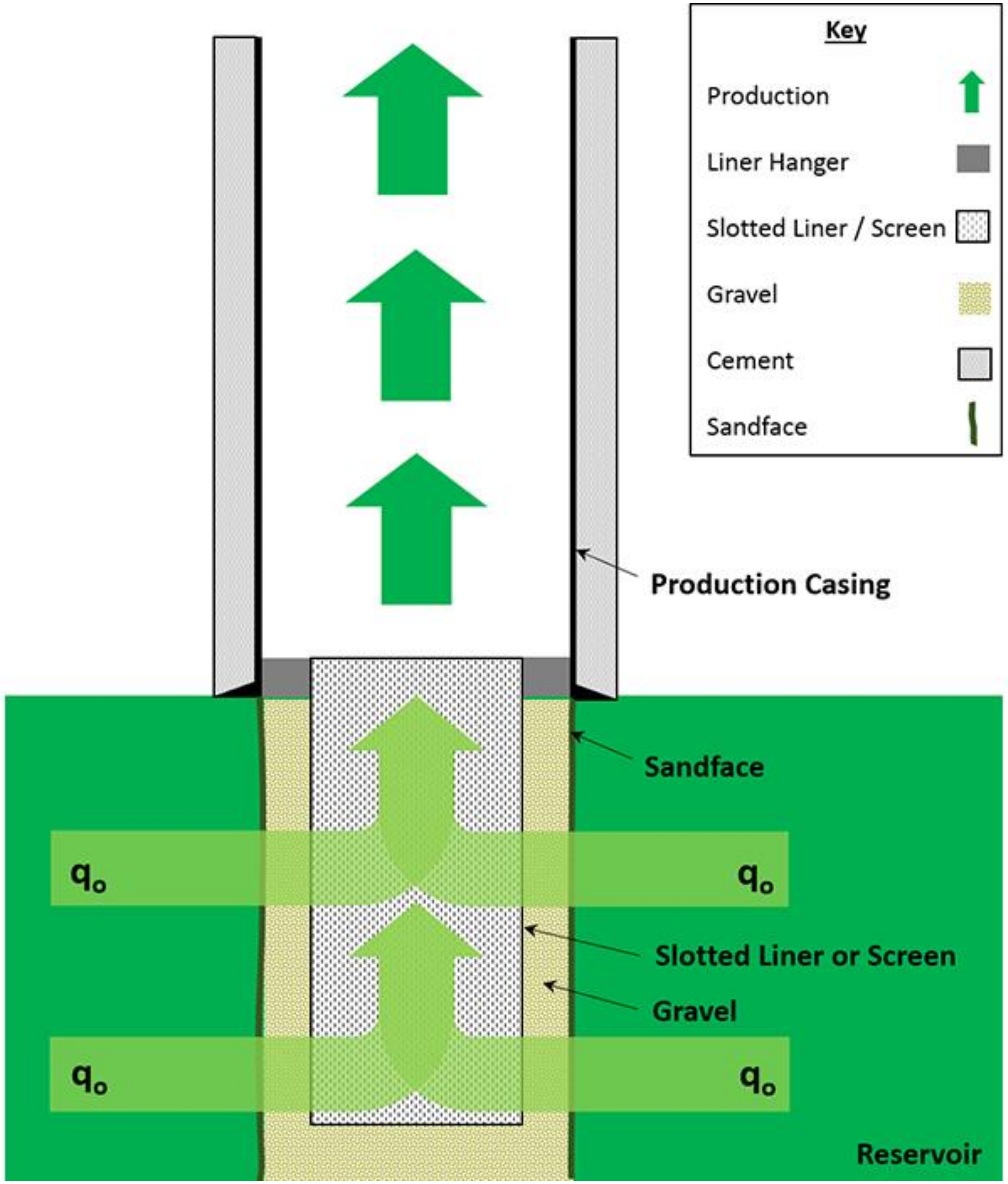
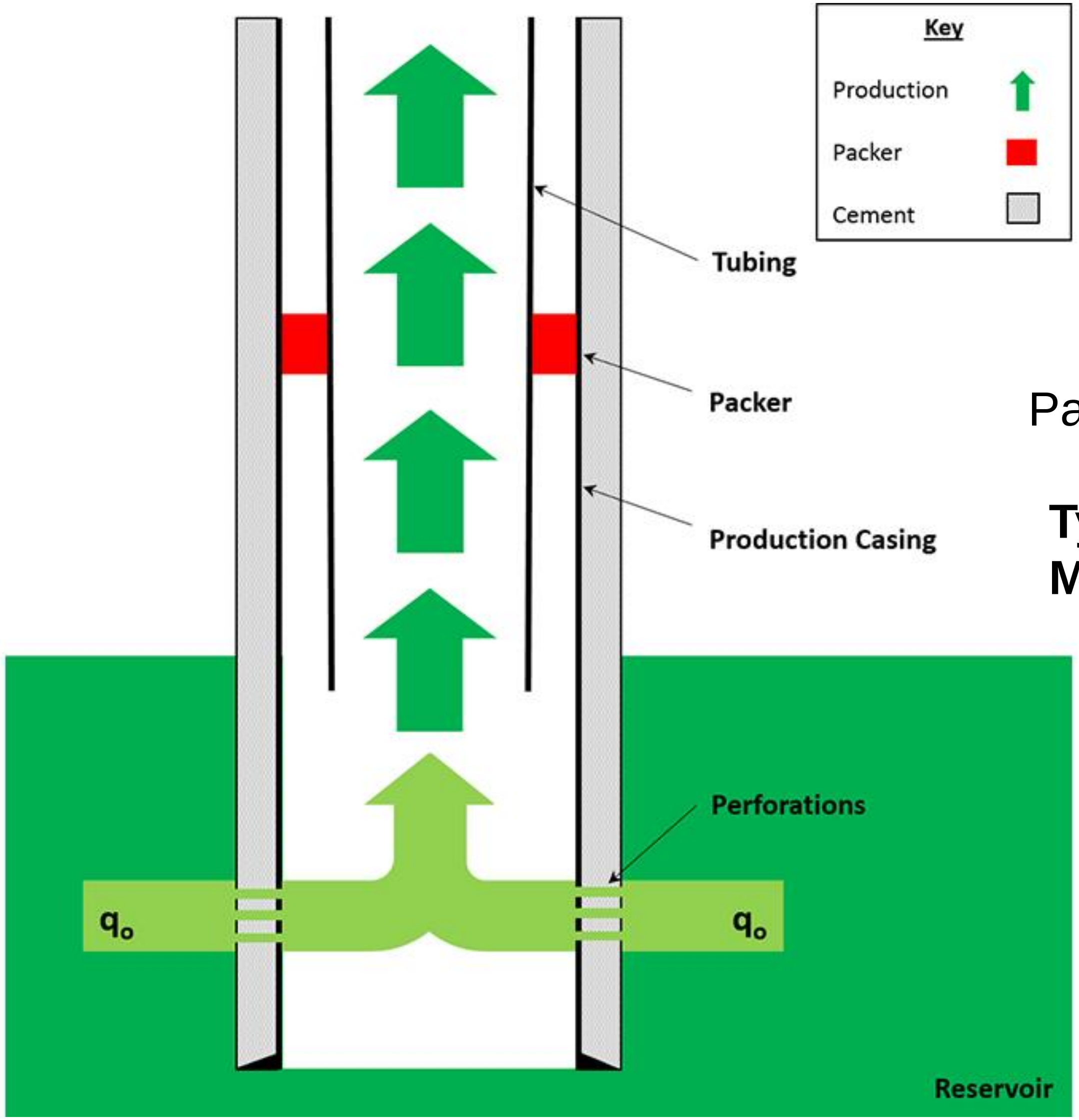


Figure 7.11b: Example of an Open-Hole Gravel Pack Open-Hole Completion



Cased and Perforated Completion

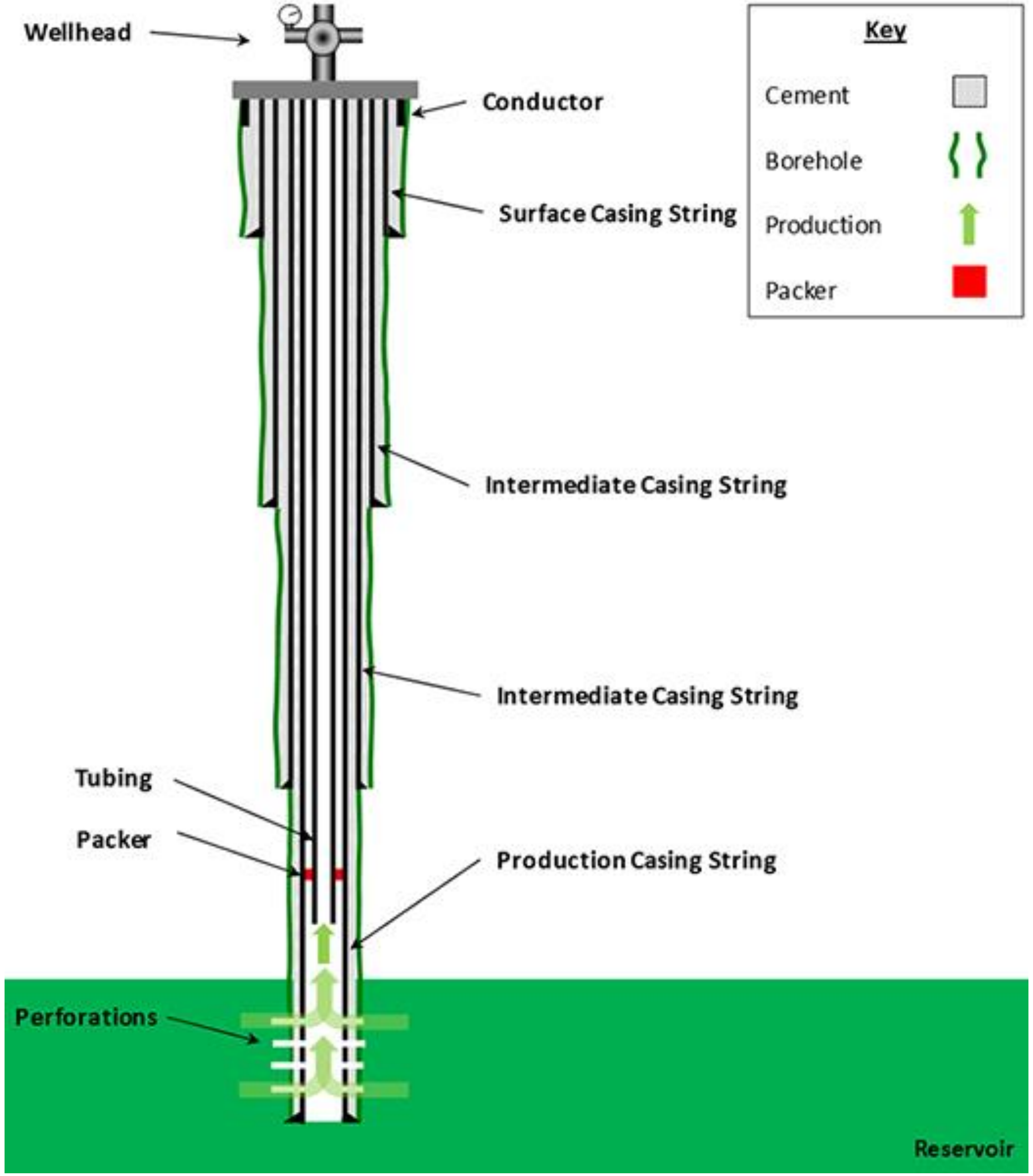


Example Cased and Perforated Completion in a Single Zone Reservoir

Packers provide isolation in the ***annulus*** of the well

Typical packers are used for Preventing Fluid Movement in annulus of the well

Packers provide a seal between the tubing and casing.



Casing Run in Modern Oil and Gas Wells

The casing strings that can be used in the oil and gas wells include:

- conductor casing
- surface casing
- intermediate casing
- production casing
- liner
- liner tie-back casing

The role of the production casing is to:

- aid in zonal isolation;
- protect the wellbore and the outer casing strings from reservoir pressures;
- protect the well and environment in case of a tubing leak.

“Conductor casing” means a casing string which is often set and cemented at a shallow depth to support and protect the top of the borehole from erosion while circulating and drilling the surface casing hole.

- Cased and perforated wells are completed by first drilling through the reservoir (or sometimes a little deeper than the bottom of the reservoir). The production casing is then run and cemented in-place. Next, the tubing string is run, and all packers are set. Finally, the perforation guns are run and fired to create the access to the reservoir.
- A perforation gun is an array of shaped charges that can be arranged in many configurations to achieve the objectives of the well. The perforation guns can be conveyed (deployed) either on wireline (wireline conveyed perforation guns) or on the tubing itself (***Tubing Conveyed Perforation***, TCP, guns). **Figure** shows a typical TCP gun.

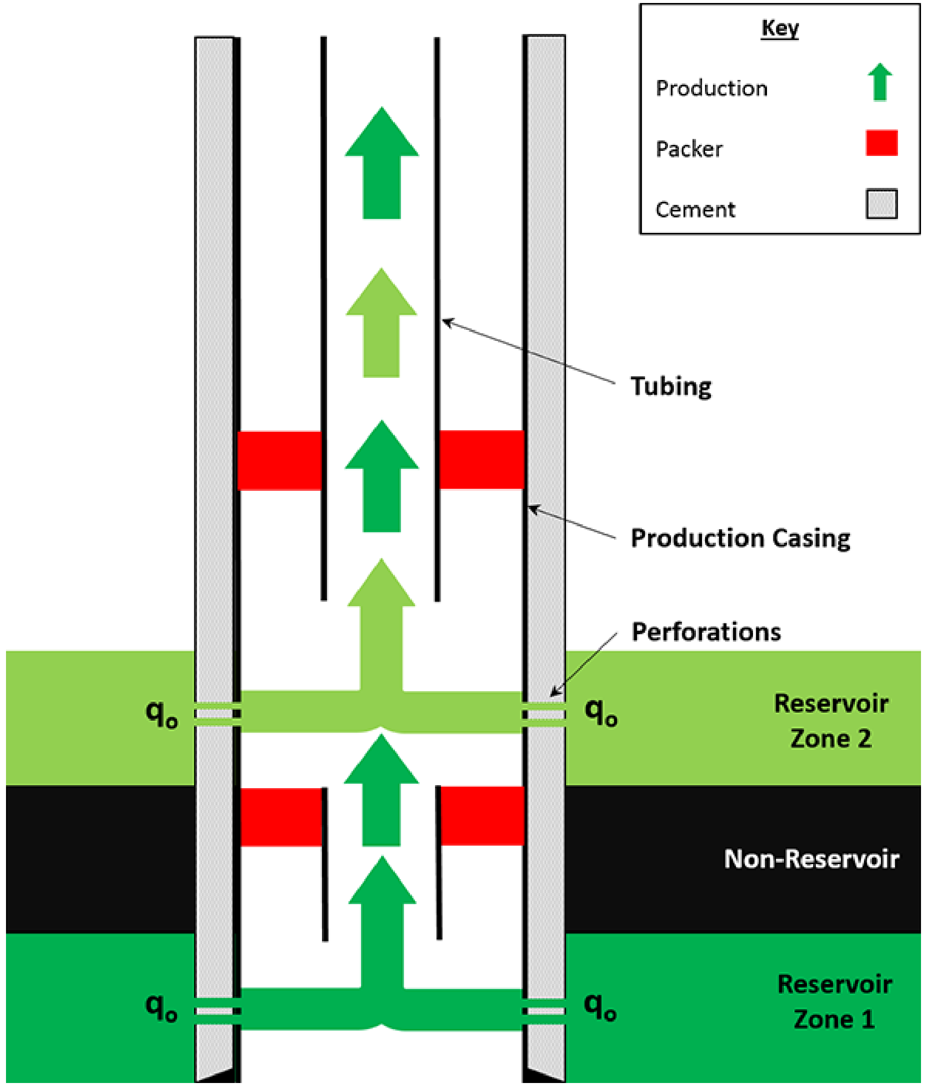
Typical Tubing Conveyed Perforation, TCP, Guns

- Cased and perforated completions provide the highest level of control for the well, and when used in conjunction of systems of ***Packers*** and ***Bridge Plugs***, are capable of providing ***Zonal Isolation*** across multiple reservoir zones.

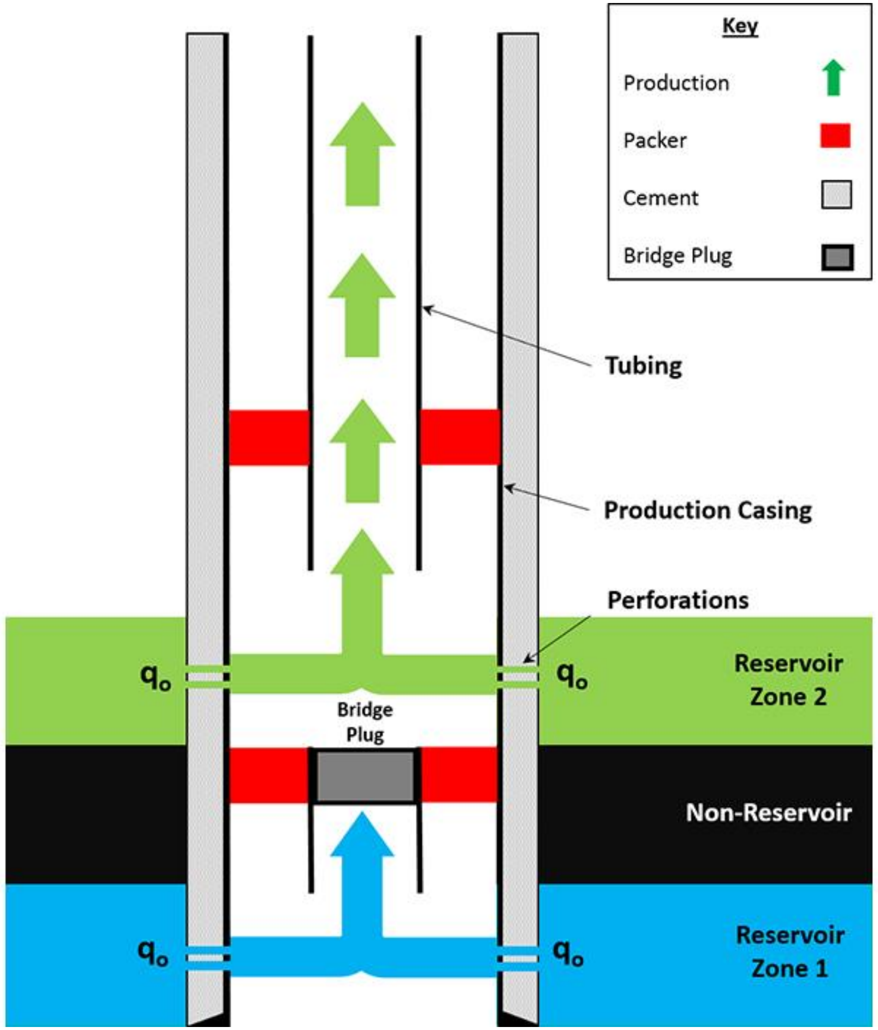
- Packers provide isolation in the ***annulus*** of the well. On the other hand, bridge plugs provide isolation ***inside the tubing*** of the well. **Figure** shows a picture of a bridge plug. The bridge plug can either be conveyed on a wireline or with a workover string. The sealing element of the bridge plug is then set inside the tubing to create the isolation. A bridge plug can be either retrievable or permanent.

Typical Bridge Plug used for Preventing Fluid Movement Inside Tubing

Example of a Cased and Perforated Completion with Packer — Tail-Pipe Assembly



Example of a Cased and Perforated Completion with Packer — Tail-Pipe Assembly and Bridge Plug



The advantages of this completion (**a Cased and Perforated Completion with Packer — Tail-Pipe Assembly and Bridge Plug**) are:

- there is no annular flow, so there are no issues with high pressures, corrosion, or erosion acting on the casing;
- the pressure gradient in the annulus and tubing are approximately equal which protects the tubing from tubing leaks.

The disadvantages of this completion are:

- lower production rates – both reservoir zones are being produced through a single tubing string. The smaller cross-sectional area for flow creates a larger pressure drop in the tubing and restricts the total production from the well;
- production from the two reservoir zones is commingled;
- only the lower zone can be isolated with a relatively inexpensive bridge plug.

Openhole Cavity Completion

- The openhole cavity completion method works only under favorable reservoir, geologic, and geo-mechanical conditions.
- The openhole cavity technique involves setting the casing only to the top of the coal formation with the drilling rig. Then, the coal is drilled out using a special completion rig (**Figure**).
- To enhance the flow back and to encourage coal sloughing in the wellbore, compressed air is injected into the reservoir. Then, the well is allowed to rapidly flow back water, gas and coal. This results in the formation of a cavity in the coal. The generated coal fines may be removed out by circulating the drill bit to the total depth from time to time.
- This process is repeated till the cavity is stable. Once stability is attained, the well is left openhole, or it is completed using a perforated, uncemented liner.

Sloughing: collapse or slide into a hole or depression

- Completion of coalbed gas wells is usually performed by using open-hole techniques to under-ream the coal reservoir.
- Normally, under-reaming of the coal is achieved by drill bits with retractable flanges of various sizes and lengths.
- The under-reamer is used to enlarge the hole and break the coal, forming a cavity around the borehole; hence, this technique is sometimes called cavitation.
- Enlargement of the hole in the reservoir effectively increases the wellbore diameter and the surface area (e.g. fracture/cleat surfaces) in the coal for gas desorption.
- The procedure of cavitation is succeeded by a series of repetitive pressurization, depressurization, and cleanup of the hole performed by a specially designed completion rig.

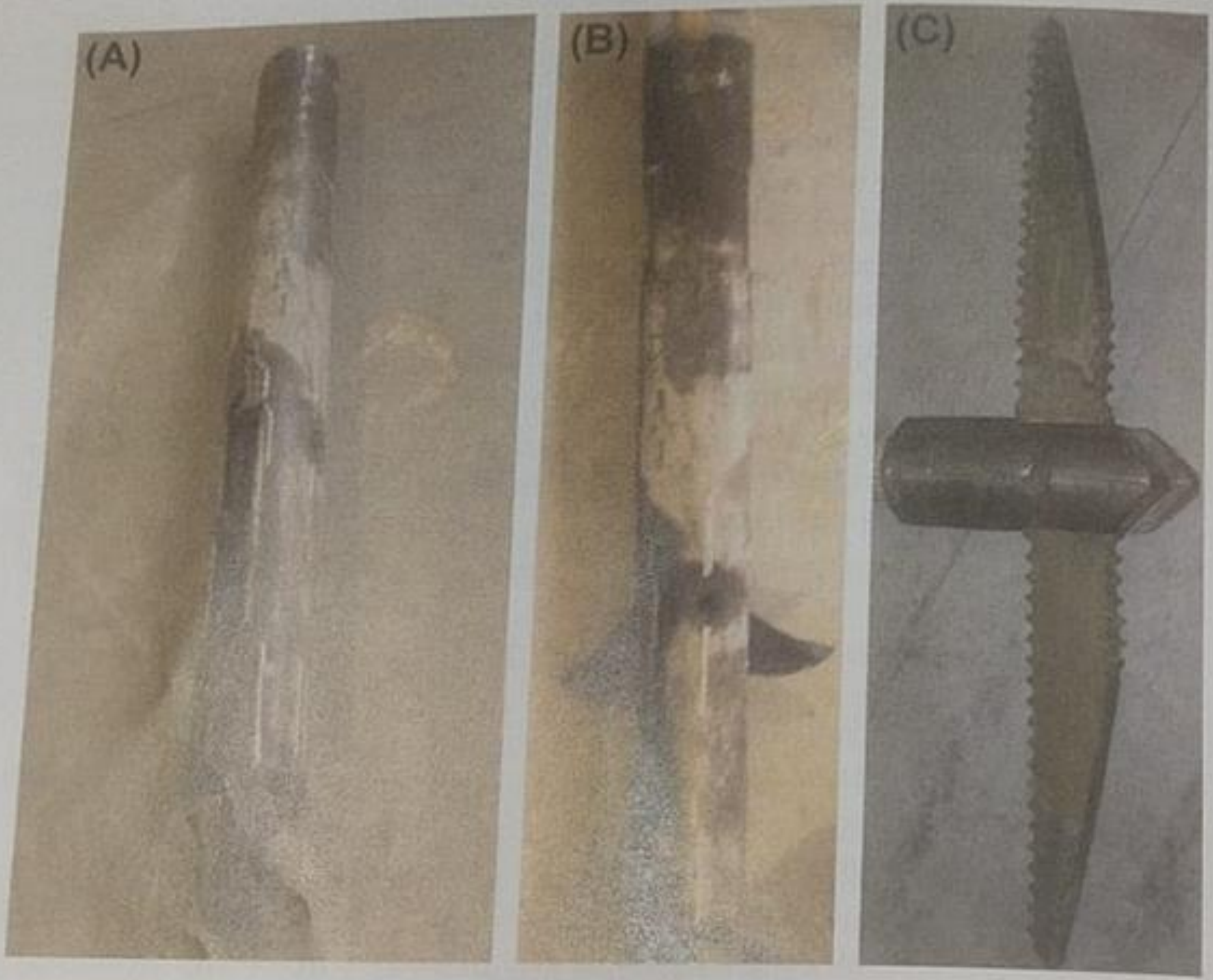
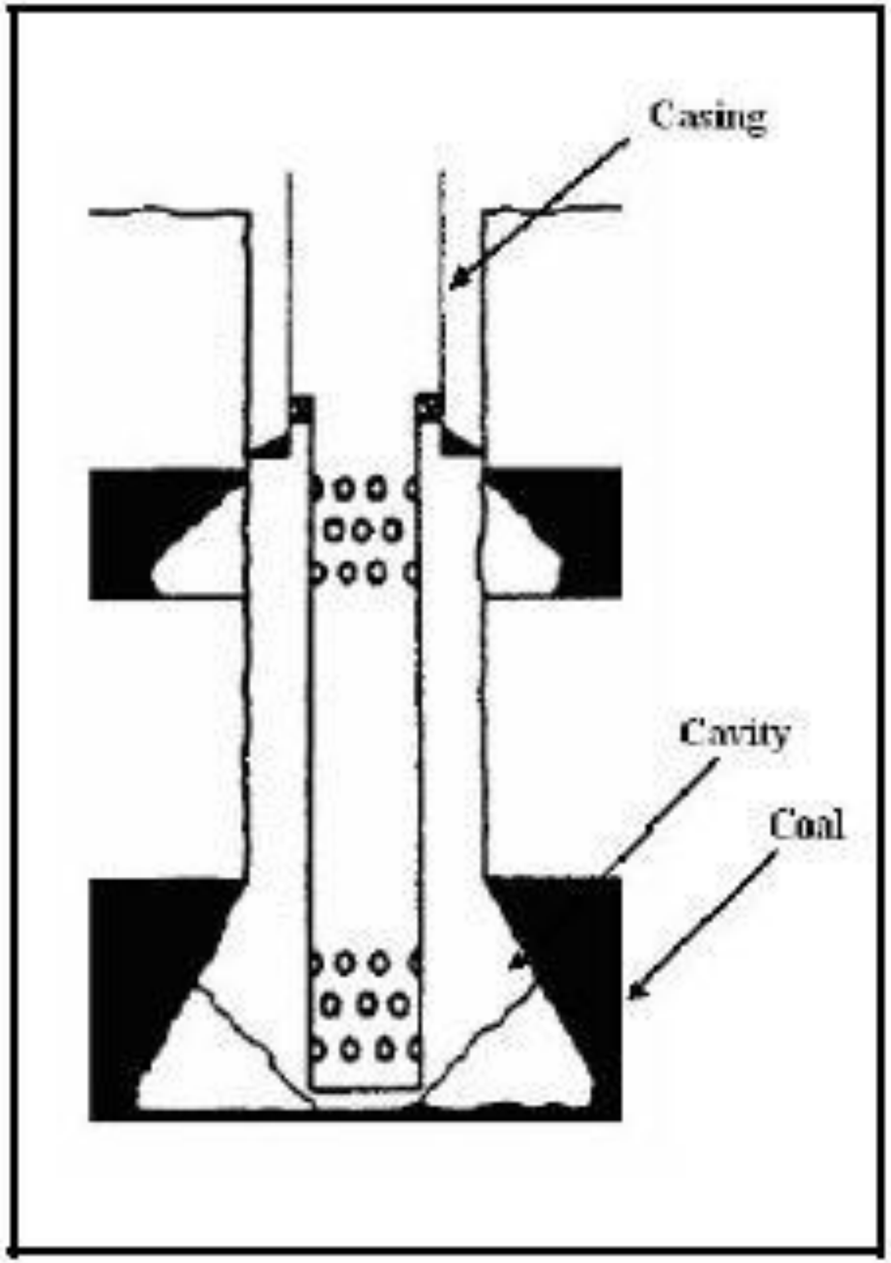
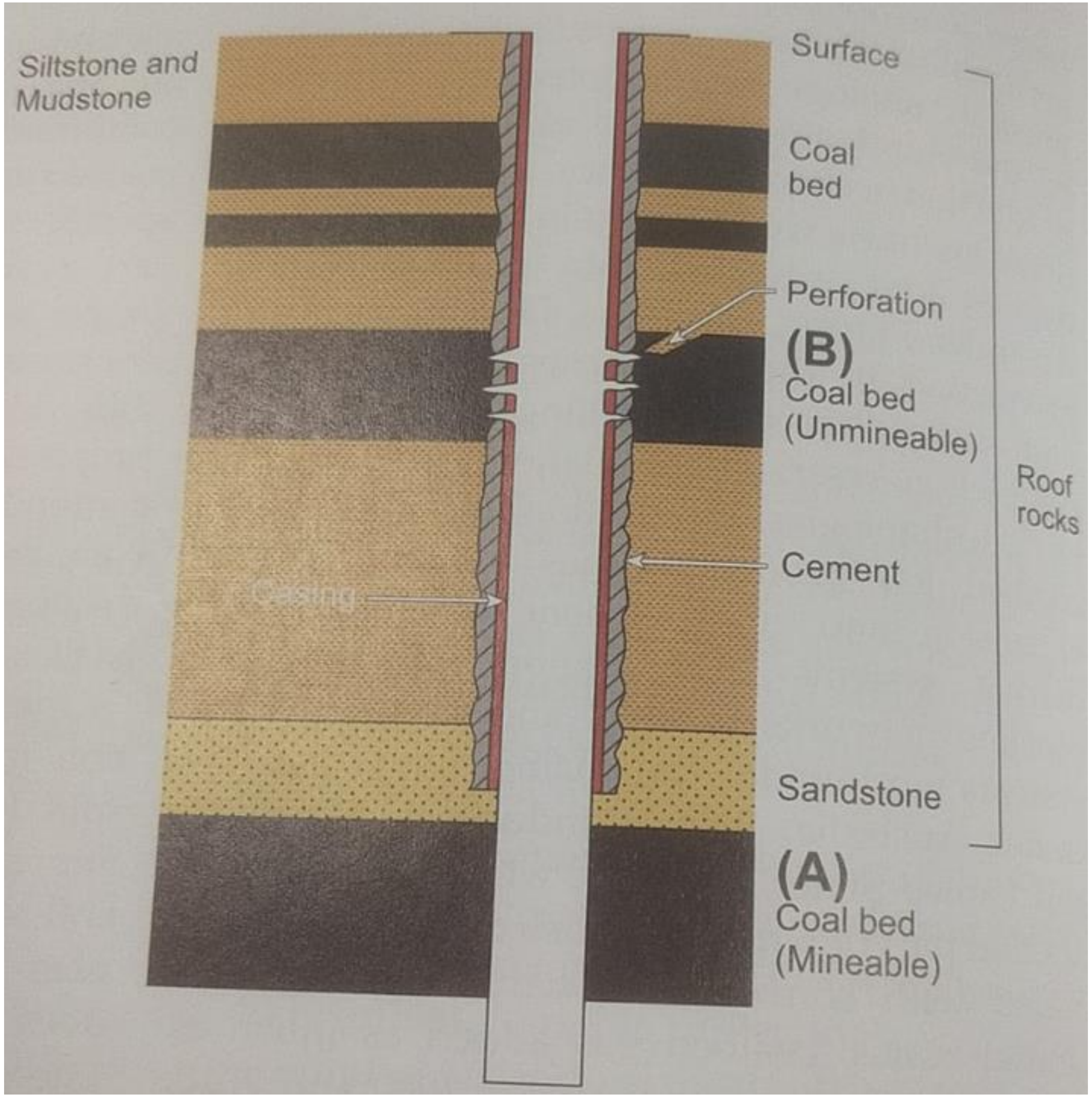


FIGURE 7.11 Scissor-bladed under reamers of varying diameter sizes used in the Powder River Basin in Wyoming, United States. (A) Retracted blade. (B) Deployed blade. (C) Double-serrated blade. *Photographs courtesy of Tom Doll.*



Openhole cavity completion



Schematic diagram showing vertical coalbed gas well used in the coal mining industry to extract coalmne methane in front of mining. (A) Open-hole completion in mineable coalbed, (B) Cased-hole completion in unmineable coalbed in the overlying roof rocks perforated for stimulation.

Topset and Under Ream

- A modified version of the openhole completion is the topset and under ream method that is used to produce coalbed gas from shallow coal seams.
- In this method, wells are drilled to the top of the coal and casing is set. Then, the well is drilled through the coal and under reamed to enlarge the borehole to enhance production and to remove permeability damage caused by drilling.
- Wells are then stimulated by pumping a small quantity of water to remove the damage caused to the formation by drilling.
- No proppant is used, as the permeability of the reservoir is already very high.

- Topset and under ream wells are successful because:

✓ **Permeability of the coal bed is very high**

✓ **Coal beds are thick and continuous**

✓ **Coals are shallow, and as a result the cost of drilling involved is low**

✓ **Completions are very simple**

✓ **The stimulation treatment used is simple and inexpensive**

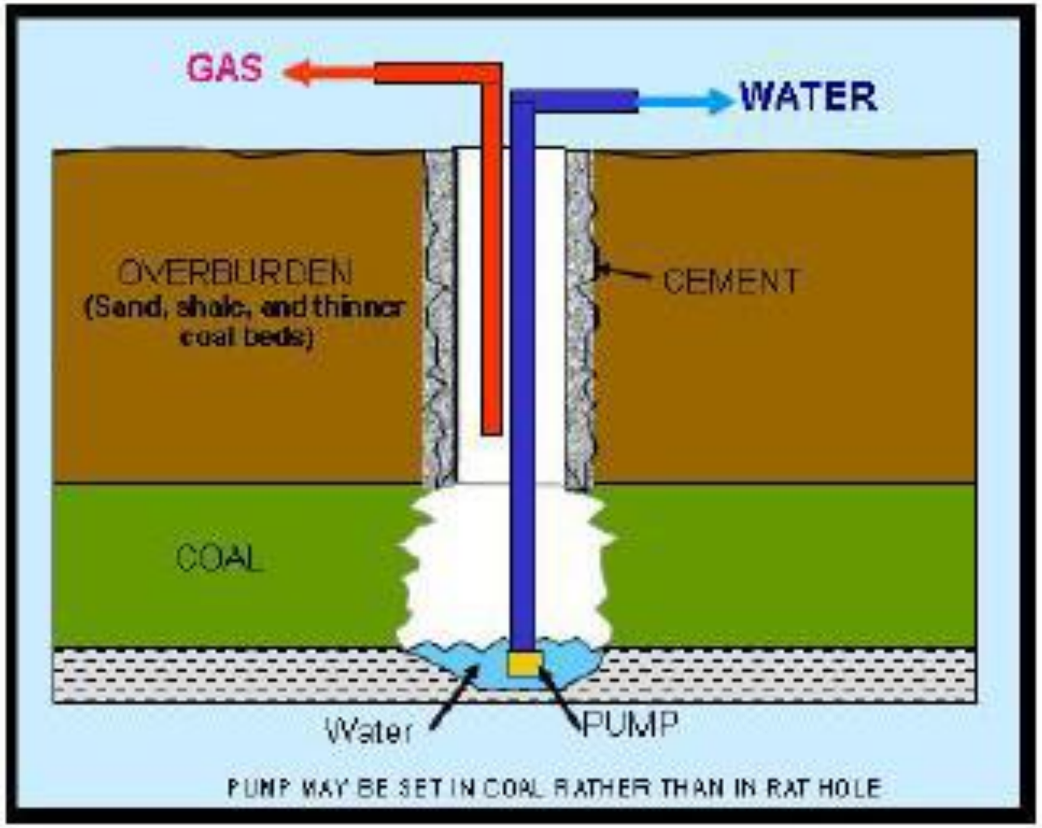
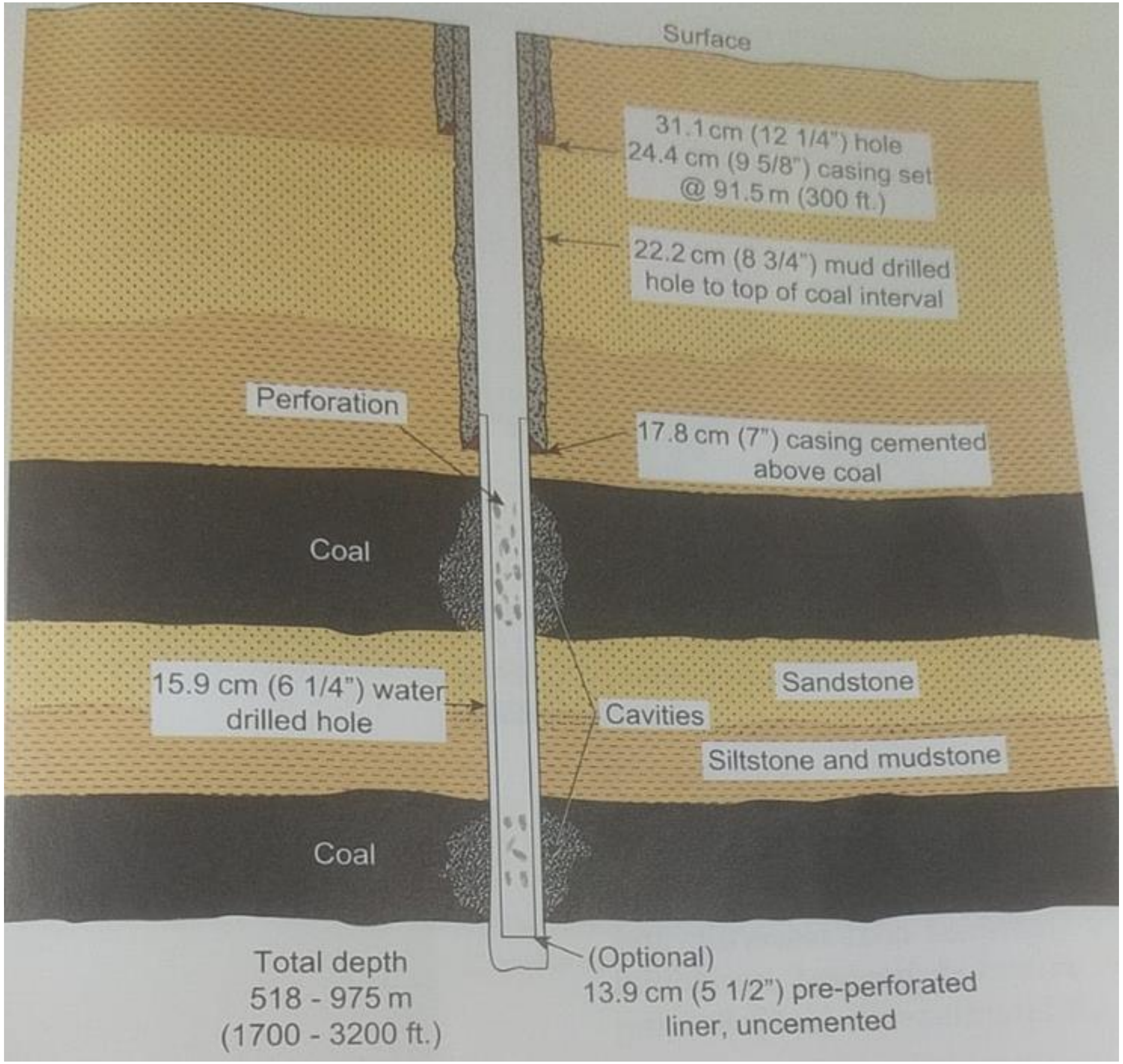


Figure : Topset under reamed well



- Figure shows a standard drilling operation for a coalbed gas well in the western coal basins in the United States to include three stages starting with a hole from the surface to about 91.5 m depth (or shallower) at about 31.1 cm diameter to set a 24.4 cm surface steel casing and set cement.
- This stage is followed by redrilling the hole using water-based mud medium (or air and other drilling fluids in various situations) to a 22.2 cm diameter hole, which is bored to the top of the coal cased with a 17.8 cm diameter steel tube and cemented to the top of the coal.
- Finally, the well is completed by drilling the hole with water through the coal and/or underlying coalbeds to total depth.

Cased Hole Completion

- The cased-hole completion is the most commonly used for coal bed completion type. It is used somewhere in most producing basins, and it is the most common completion in medium-to-low permeability coal beds. This completion is successful because it gives the best control over coal integrity and the stimulation of individual seams.
- Cased-hole completions are to solve the coal sloughing problems and to allow fracture stimulation treatments.
- In most CBM cased-hole completions, the casing is perforated, and the coal is hydraulically stimulated. Thus, the hydraulic fracture design is an integral part of the cased-hole completion design.

- The cased-hole completion is suitable for almost all types of coal seams, other than high permeability coal seams.
- The most important factor in selecting a cased-hole completion is the economics involved and the type of stimulation treatment. Depending on the number of seams to be produced, the cased-hole completion could be single seam or multi-seam completion.

Fundamental Reservoir Parameters

Factors to be considered in the selection of the drilling and completion technique include

✓Reservoir thickness
✓Coal cleat/fracture permeability/porosity
✓Reservoir pressure
✓Gas saturation and gas composition
✓Number of seams
✓Geologic complexity
✓Minimum completable thickness
✓Dip
✓Coal competency/hole integrity/risk of collapse
✓Surface access
✓Economics, capital, and operating costs

In general, the following principles are suggested:

- Coal seams with lower permeability require a greater degree of stimulation, such as hydraulic fracturing or cavitation, to achieve economic production rates and cumulative recovery.
- Thick, highly permeable coal seams require relatively little stimulation, while low-permeability coal seams may require stimulation techniques or horizontal drilling.
- Large numbers of coal seams or highly structured, geologically complex coal seams may limit the optimal candidates to vertical-well-completion options only.
- Surface access or limitations in local services may drive the drilling and completion decision.

Vertical Well, Openhole Underream Completion, Single Seam

The major steps for this drilling and completion technique are

- ✓Drilling the production hole to the top of the coal seam
- ✓Running and cementing casing
- ✓Drilling a hole through the coal seam
- ✓Increasing the diameter of the hole by a technique known as underreaming (Fig. 1)

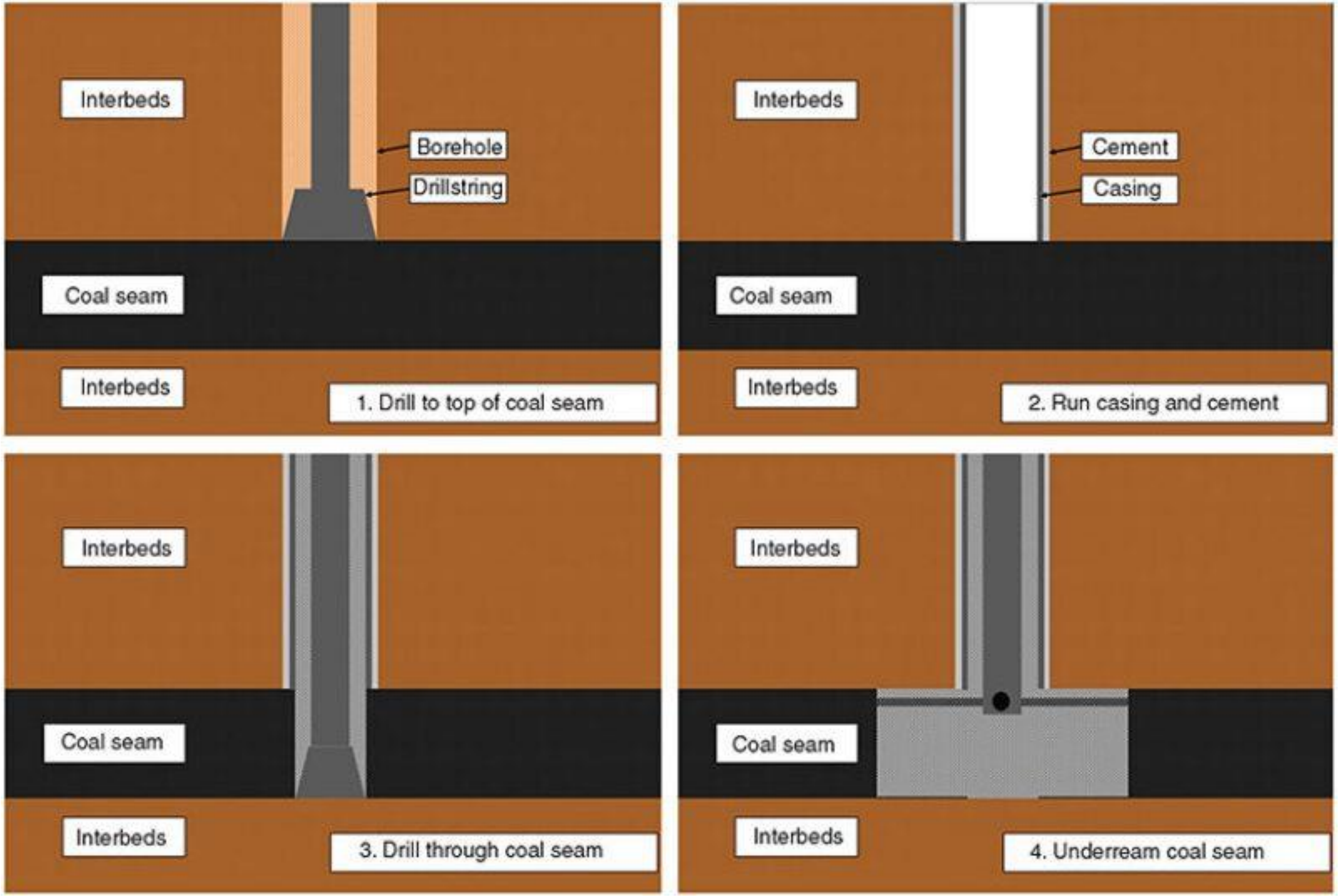


Fig. 1—Vertical openhole underream completion.

- From a reservoir-engineering perspective, the stimulation effect is achieved because the resulting underreamed hole diameter is larger than the original hole diameter.
- This type of technique is best suited for thick, vertically continuous, highly permeable coal seams. The primary advantage of this technique is that it is very inexpensive relative to other options.

- Disadvantages for this technique are that caving of the formation may cause fill, which, in turn, may cause production problems; completion of deeper coal seams is nearly impossible; and completion of upper coal seams may be difficult and complicated.

Vertical Well, Cased and Openhole, Underream and Perforate Completion, Multiseam

- This technique is a variation of the preceding technique.
- In this technique, a hole is drilled to the top of the main target coal seam and casing is run and cemented as before.
- After underreaming, a bridge plug is set above the primary completion interval, and additional coal seams are completed according to typical plug-and-perforation techniques.

Vertical Well, Openhole Cavity Completion, Single Seam

- This drilling and completion technique (Fig. 2) is similar to the vertical-well openhole single-seam underream completion in that a hole is drilled to the top of the coal seam, where 7-in. casing is run and cemented.
- After the coal seam is drilled, instead of performing the underream technique, air compressors are used to inject air (and sometimes water and air) into the coal seam at a high rate and pressure.
- After injection, the well is opened to the atmosphere and the high-pressure air is allowed to escape from the coal seam. This process causes individual pieces of coal to cave into the wellbore, after which they are circulated out of the wellbore. This process is repeated many times (perhaps 15 times or more).

- At the completion of the cavity process, the well may be left open hole or a perforated liner may be installed.
- The stimulation achieved by the cavitation process can be attributed to two main mechanisms—first, the increased diameter of the wellbore caused by the cavitation process; second, coal cleat relaxation in the area beyond the cavity, which increases the aperture of the cleat system, creating an additional stimulated zone.

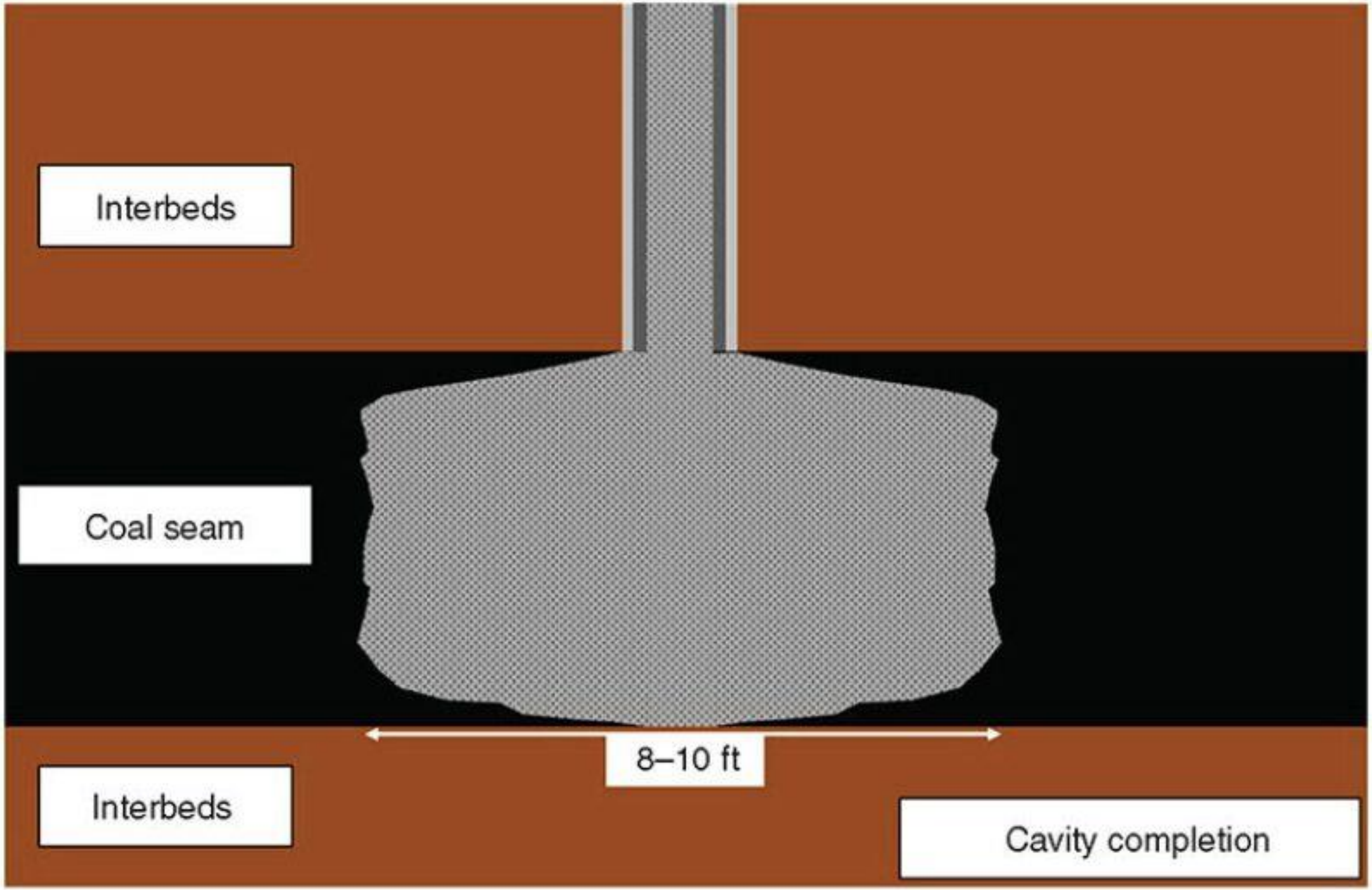
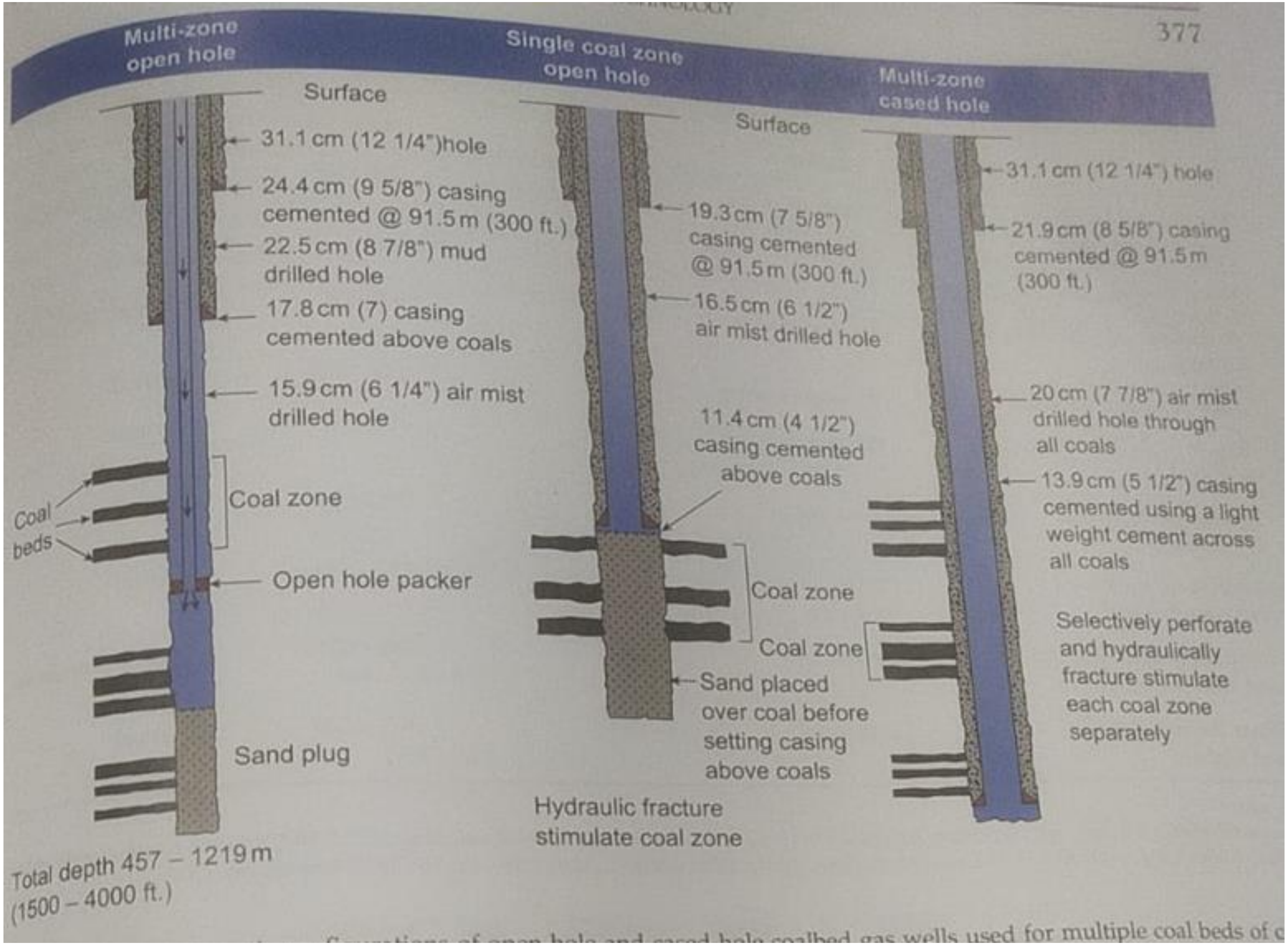


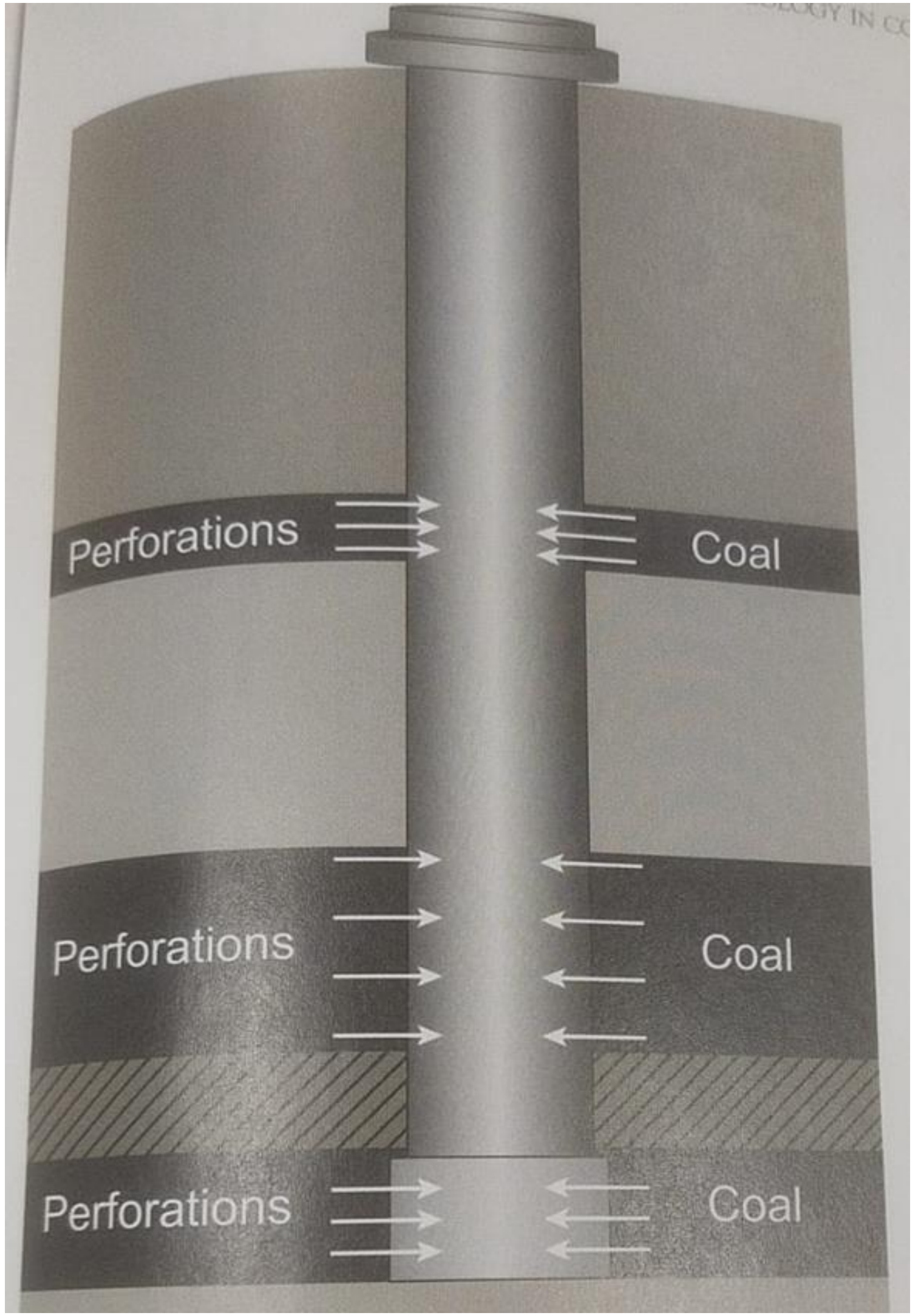
Fig. 2—Vertical open-hole cavity completion.

Vertical Well, Cased and Perforated Hydraulic-Fracture Completion, Multiseam

- This technique is by far the most common technique for drilling and completing CBM fields, especially where multiple completable seams are encountered and many or most of them need to be hydraulically fractured to achieve economic flow rates and cumulative recoveries.
- The first zone to be completed is perforated (several individual coal seams may be included in each stage) and hydraulically fractured. The zone is then isolated, and the next zone is perforated and hydraulically fractured. Zonal isolation can be accomplished by several techniques such as plug-and-perforation, ball-and-baffle, or multizone-stimulation technology.



Schematic configurations of open-hole and cased-hole coalbed gas wells used for multiple coalbeds of coal zones.



- Figure shows perforation of multiple coalbeds. Each coal in multibed completion is separately perforated.
- The problem with this technique is optimizing gas production from each coal reservoir resulting in different hydrostatic pressures (e.g. weight of groundwater applied to the coalbeds or hydrostatic head).
- For example, if the groundwater surface for the entire coal zone is above the uppermost coalbed, the hydrostatic pressure will be higher in the lowermost than in the uppermost coalbed.
- This differential hydrostatic pressure imposes difficulty in uniformly degassing the underpressurized coalbeds in the targeted coal zone.

- Advantages of this technique are that all desired coal seams can be sequentially completed in stages, leaving nothing behind pipe. Coal particles and fines are generally well-controlled behind pipe, minimizing formation caving and associated production problems such as pump and equipment plugging and hole fill-up.

- Disadvantages may include somewhat higher costs and longer completion times, depending on the number of hydraulic-fracture stages. Wells may experience initial well-cleanup issues, such as sand and coal-fines production. Operators may control the initial rate of water-level reduction to manage these problems.

Vertical Well, Openhole Underream With Intercepting Single or Multiple Surface-to-Inseam Openhole Horizontal Wells, Single Seam

- In this technique (Fig. 3), a vertical well is drilled with the "vertical well, openhole underream, single seam" method described earlier.
- A target is then placed in the underream section, and the surface-to-inseam horizontal well is drilled, typically from 1 km away, and intersects the underreamed section of the vertical well. Sensors in the drill string are used to detect the target. Two or three passes may be required to hit the target.
- Typically, a perforated or slotted plastic liner is inserted into the open and unstimulated horizontal well to prevent collapse of the coal.

- After cleanout of the openhole section of the vertical well, artificial-lift equipment is installed, with the pump typically set in or just above the underream section.

- Advantages of this technique are that a high recovery of gas in place can be achieved in a short period of time relative to that achieved by vertical wells, and it can be used in areas where hydraulic-fracturing capability is lacking.
- Disadvantages include an inability to complete more than one coal seam with each set of inseam wells. Inseam-well-stability issues can cause partial or complete loss of an inseam-well section.

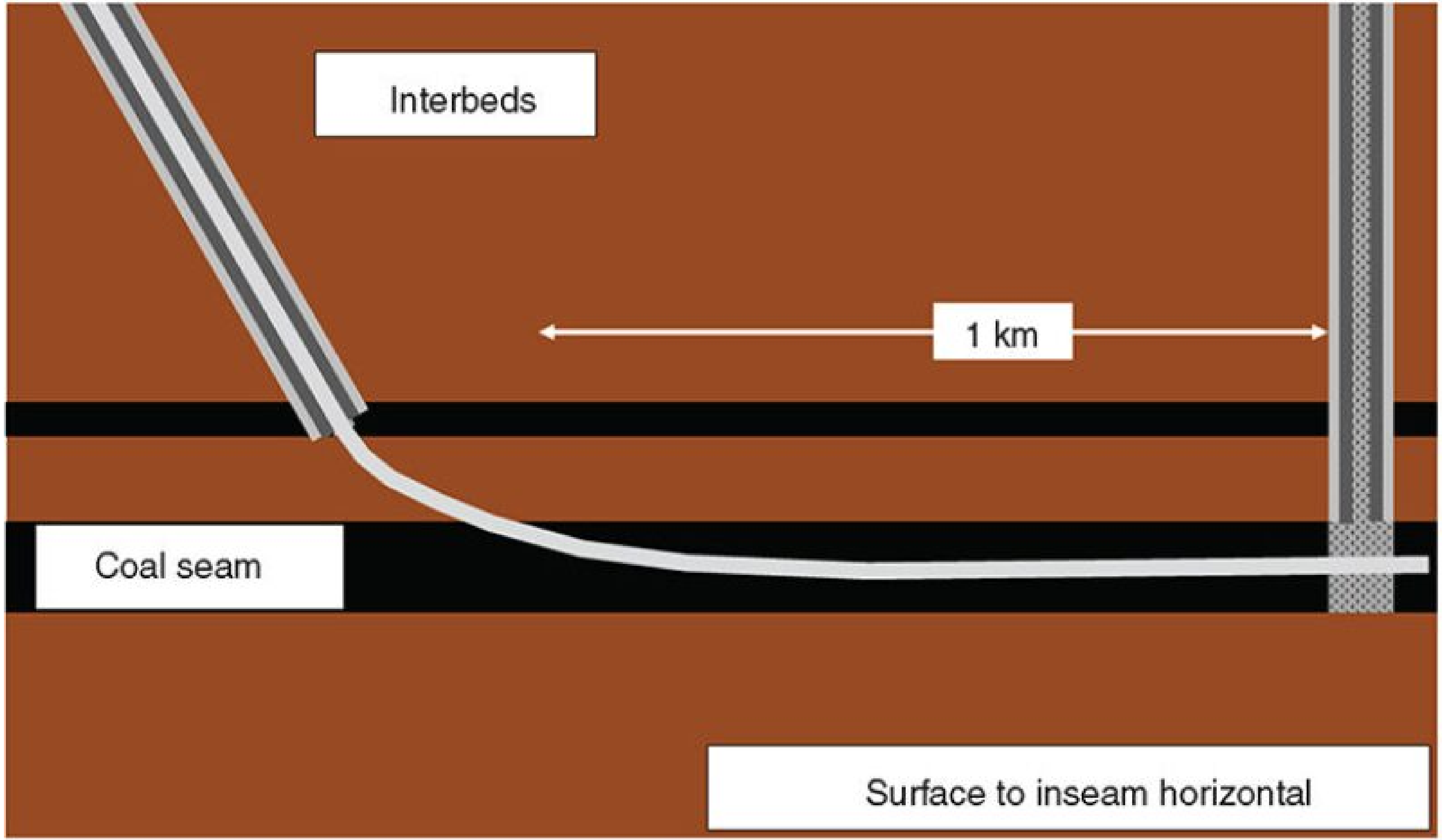


Fig. 3—Surface-to-inseam horizontal well.

Vertical Well, Openhole Underream With Intercepting Surface-to-Inseam Openhole Multilateral Horizontal Wells

- This technique is similar to the preceding technique in that a vertical well is drilled to the top of the coal seam and production casing is run and cemented. The coal seam is then drilled and underreamed.
- At this point, a nearby surface-to-inseam well is drilled to a depth near the top of the coal seam. A tight-radius turn is made, and a horizontal inseam well intersects the underreamed portion of the vertical well (Fig. 4).
- The inseam well is then drilled through the coal, typically for approximately 0.7 km. The drill string is then retracted, and lateral wells are drilled into the coal seam in a pinnate pattern.

- Production is by pump in the vertical well. This type of drilling and completion technique has the same advantages and disadvantages as the surface-to-inseam technique previously discussed, with two additional disadvantages.

- It is not possible to install plastic liners in the multiple lateral well sections, and, in relatively thin coal seams and where geologic complexity exists, core-hole drilling may be required to locate the inseam-well sections properly.

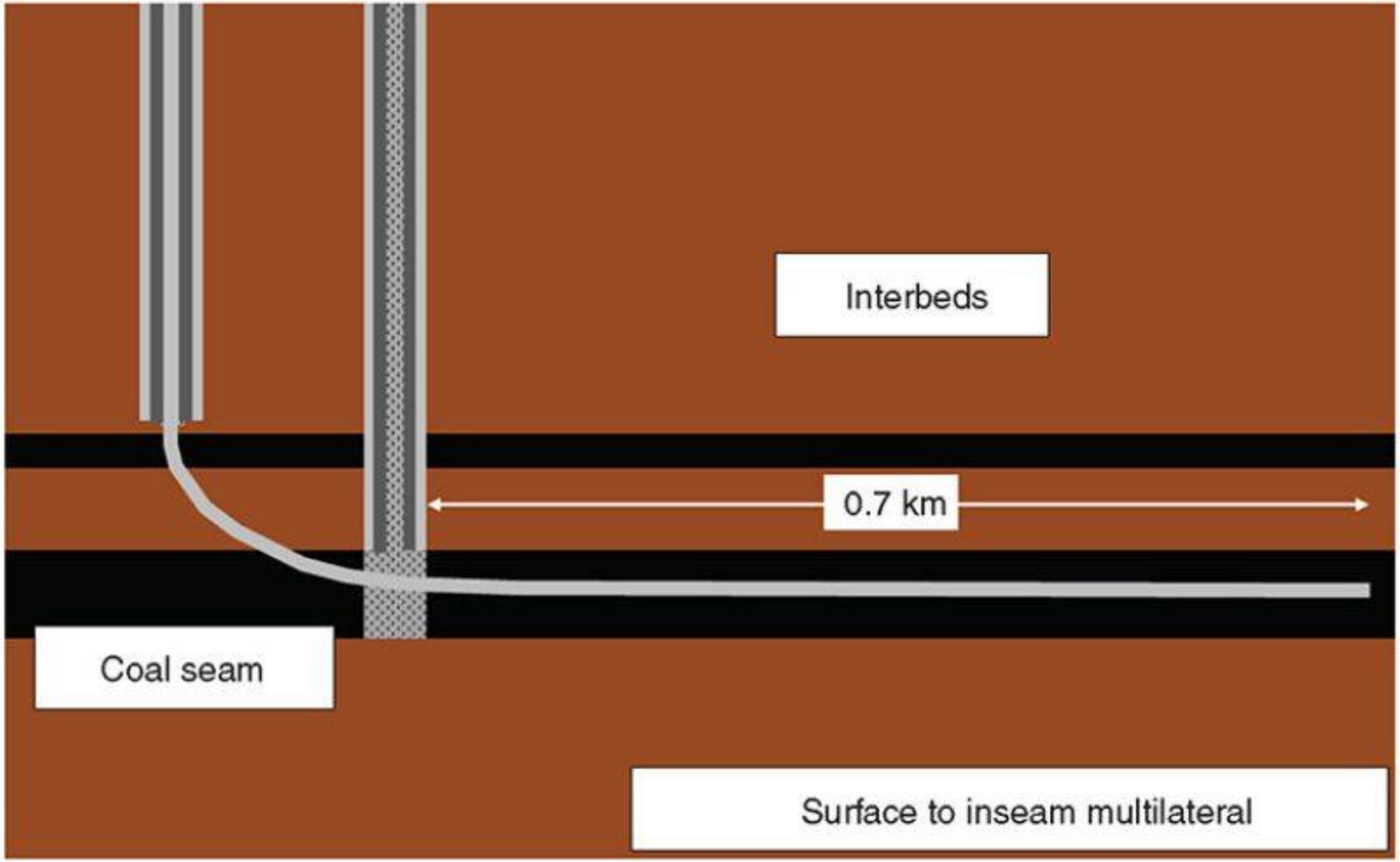


Fig. 4—Surface-to-inseam multilateral well.

- https://www.e-education.psu.edu/png301/node/893
- https://jpt.spe.org/drilling-and-completion-technique-selection-coalbed-methane-wells