Basics of Drilling Engineering I

Prof. Dr. M. Enamul Hossain

CEO & President
NSRIC Chair Professor in Sustainable Energy
Online Education Division (OED)
NSRIC Inc.
London, ON, Canada
E-mail: ceo@nsric.ca

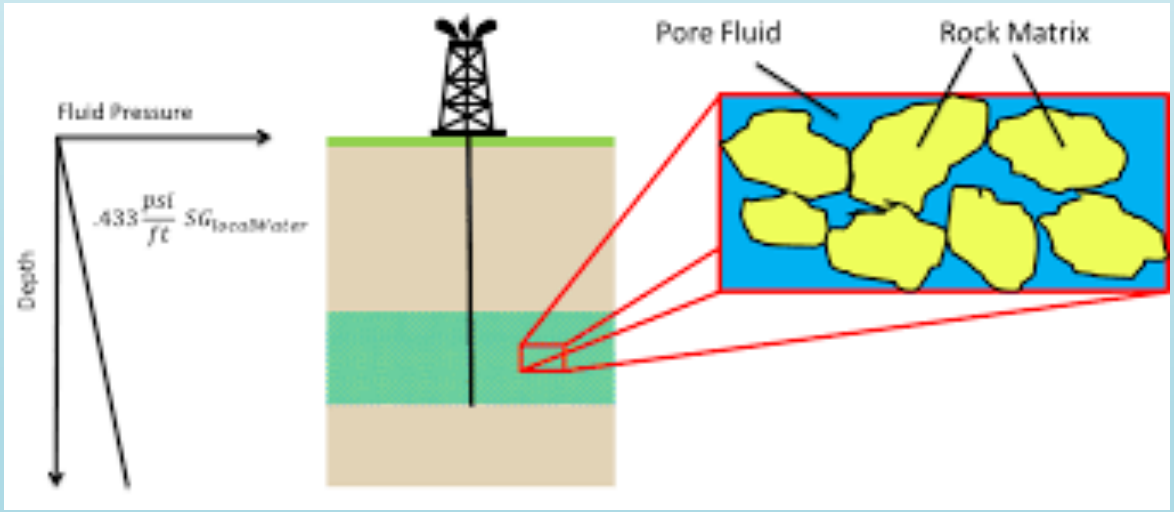
Module III, Lecture 16
(Formation Pressure Drilling – I)

Formation Pressure

Definition:

Formation pressure (or pore pressure) is the fluid pressure found within the pore spaces of the formation.

It can be expressed as an average vertical pressure or equivalent mud weight. The unit of pore pressure is psi, ppg, g/cc etc.



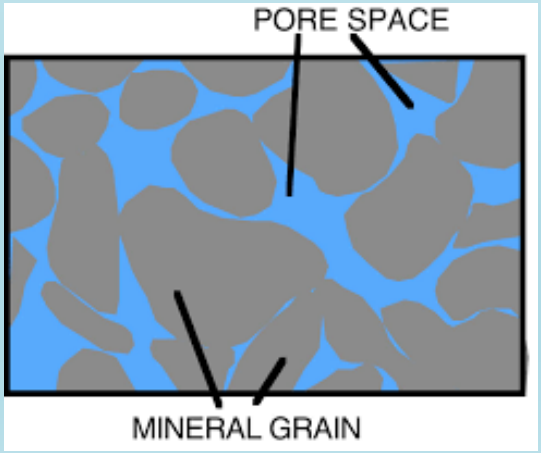


Figure 1 Formation pressure

Formation Pressure Cont..

Why do we Need to Know?

A knowledge of formation pressure (or pore pressure) is essential in drilling engineering since it affects:

- Casing design
- Mud weight
- Penetration rates
- Problems with stuck pipe
- well control

It is very important because of the necessities of the prediction and detection of high pressure zones where there is a risk of blowout. Such zones are usually associated with the thick shale sequences which have trapped the connate water and normally released during deposition.

Formation Pressure Cont..

How does Formation Pressure Develop?

1. As sediments deposit to form sedimentary layers, the fluid (water) is trapped in small pores which form during the sedimentation process.
2. As the sedimentation process continues, an increasing portion of the overburden stress is carried through grain-to-grain contacts.
3. Under normal compaction, the pore fluid remains in communication with the surface.

Formation Pressure Cont..

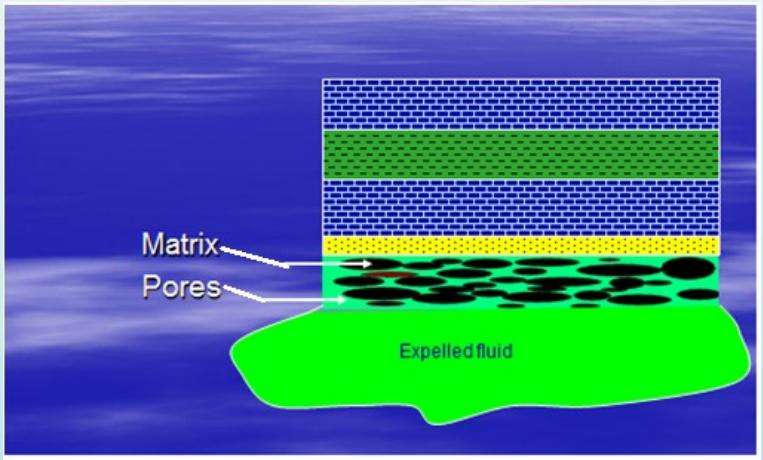


Figure 2 Water expelled out from the pore space

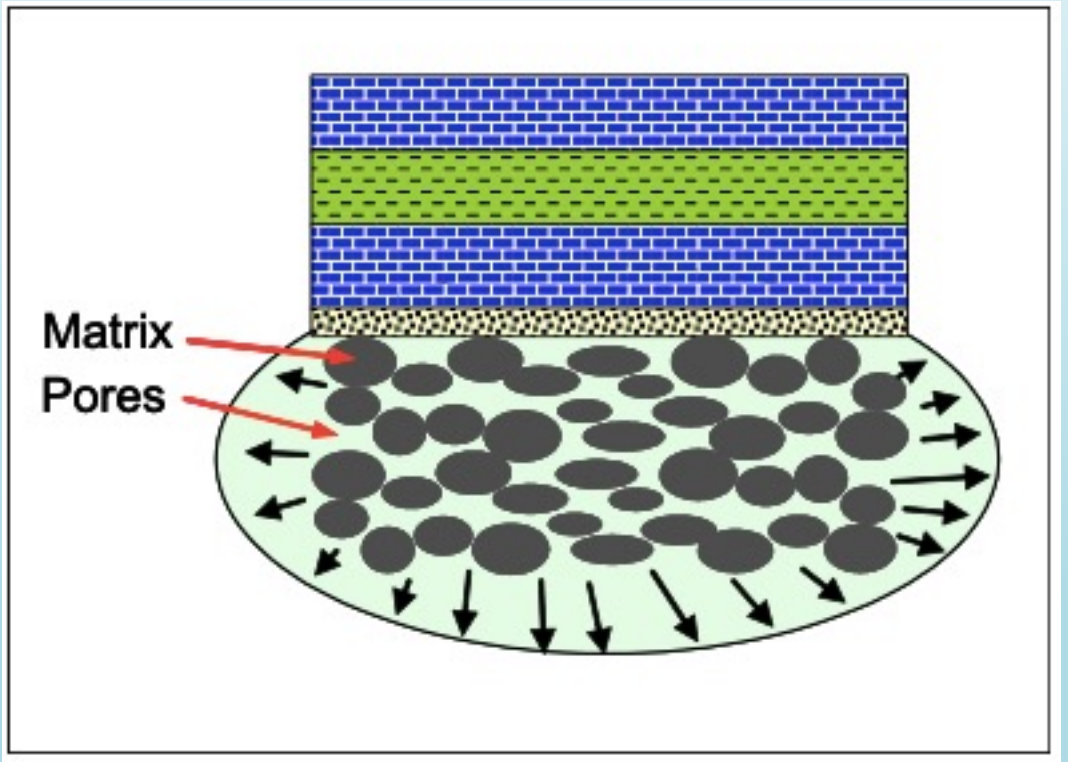


Figure 3 Abnormal pressure development in the formation

Formation Pressure Cont..

Potential reasons for abnormal pressure gradient of the formation

- Artesian systems
- Structural reasons
- Tectonics
  - Faults
  - Salt or shale diapirs
  - Others
- Surface erosion
- Rock diagenesis
  - Sulfates
  - Precipitation
  - Clays
- Thermal effects
- Osmosis through shale
- Biochemical effects
- External pressure sources
  - Natural
  - Man-made
- Undercompacted shale

Formation Pressure Cont..

Classification of Formation Pressure

Formation Pressures are based on pressure gradient:

i) Normal Formation Pressure

ii) Underpressured Formation Pressure

iii) Overpressure Formation Pressure

Formation Pressure Cont..

i. Normal Formation Pressure

Definition:

When formation pore pressure is approximately equal to theoretical hydrostatic pressure for a given vertical depth, formation pressure is called as normal pore pressure.

Any formation pressure above or below the hydrostatic gradient is called as abnormal pressure.

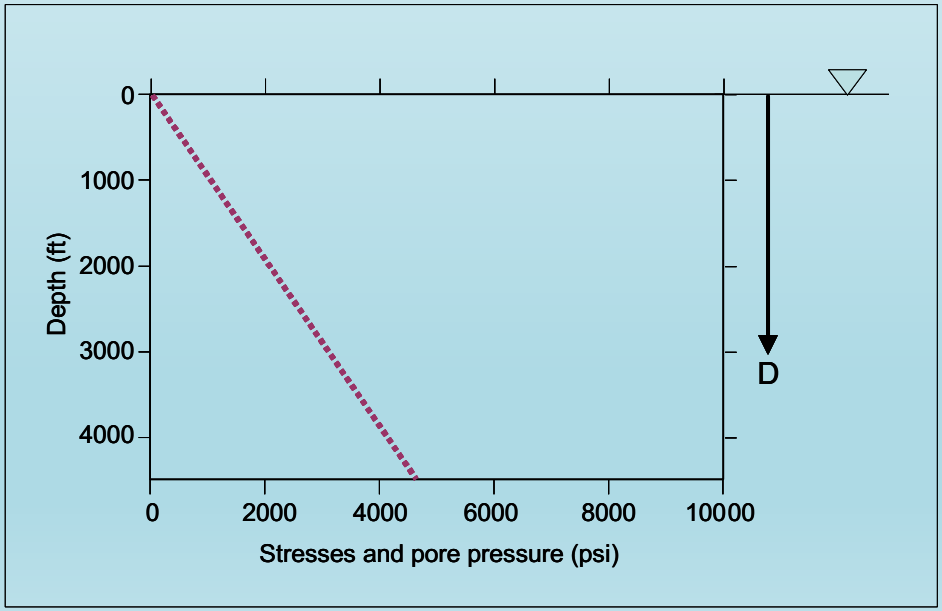


Figure 4 Normal subsurface pressure with depth

Formation Pressure Cont..

i. Normal Formation Pressure Cont..

In this case, the pore pressure, i.e., the fluid pressure within the pores, is **normal, meaning** that it is approximately equal to the hydrostatic pressure.

Example 1:

Calculate the normal pore pressure at a depth of 6000 ft below sea level can be calculated as:

Solution:

Mud weight Total vertical depth

$$HSP\ (psi) = 0.052 \times MW\ (ppg) \times TVD\ (ft.)$$

Hydrostatic pressure

[From Lesson 12, Eq. (18)]

$$Pp = 0.052(8.33)(6000) = 2600\ psi$$

Formation Pressure Cont..

i. Normal Formation Pressure Cont..

- Note that water densities vary from region to region. The normal pore pressure must be determined using the proper water density or pressure gradient. Some typical values are listed below (Table 6.2, Hossain and Al-Majed, 2015)

Table 1 Pressure gradient and density

	Pressure gradient (psi/ft)	Density (g/cm^3)
Anadarko Basin	0.433	1.000
California	0.439	1.014
Gulf of Mexico	0.465	1.074
Mackenzie Delta	0.442	1.021
Malaysia	0.442	1.021
North Sea	0.452	1.044
Rocky Mountain	0.436	1.007
West Africa	0.442	1.021
West Texas	0.433	1.000

Formation Pressure Cont..

ii. Underpressured Formation Pressure

Underpressured formation pressure is also called as subnormal formation pressure. As shown in Figure 5, the subnormal pressure is always smaller than the normal formation pore pressure which shows some very specific geographical locations on earth. Lost circulation problems and differential sticking are common problems in these areas.

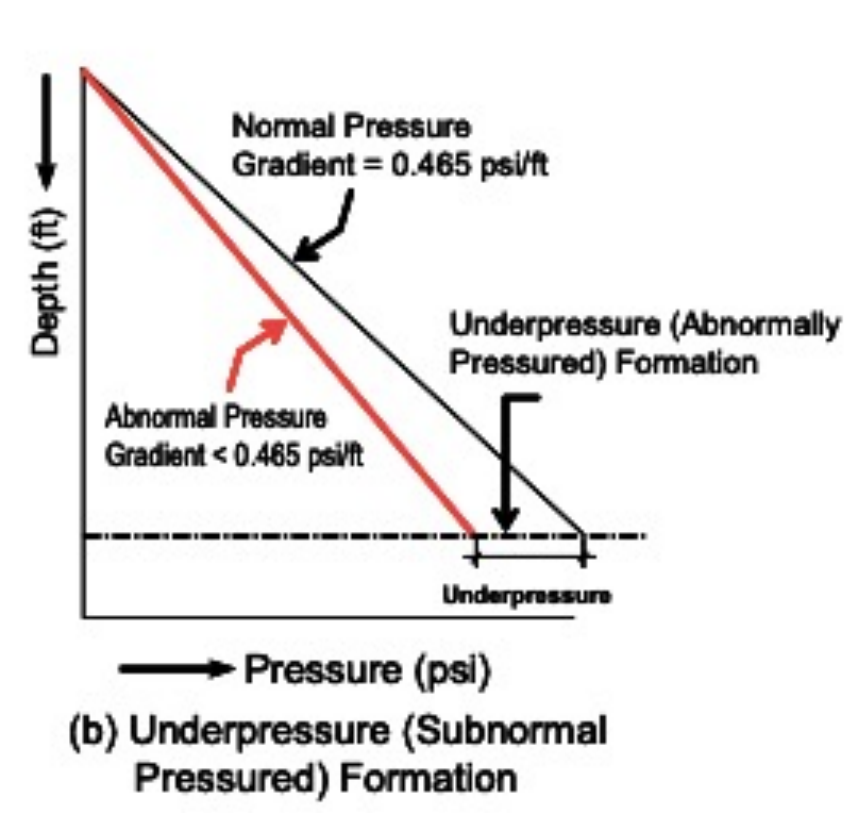


Figure 5 Variation of pressure showing underpressured formation

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism)

There are many mechanisms by which subnormal pressures occur. The major mechanisms for underpressured formation pressure are:

i) **Thermal expansion,**
ii) **Formation foreshortening,**
iii) **Precipitation,**
iv) **Epeirogenic movement,**
v) **Depletion,**
vi) **Potentiometric surface**
vii) **Faulting**
viii) **Outcrop Aquifer**

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

i) Thermal Expansion:

As sediments and pore fluids are suppressed with the increasing burial depth, the temperature rises. In such case if the pore fluid is allowed to expand, the density will decrease which results a diminution in pressure.

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

ii) Formation Foreshortening: During a compression process of the formation beds, there is some bending of strata as shown in Figure 6. Due to this action, the upper bed A will bend upward, while the lower bed C will bend downwards. The intermediate bed B must expand to fill the void and so create a subnormally pressured zone. This is assumed to apply to some subnormal formation zones in Indonesia and the USA. It is noted that this action may also cause overpressures in the top and bottom beds (i.e., Bed A and Bed C).

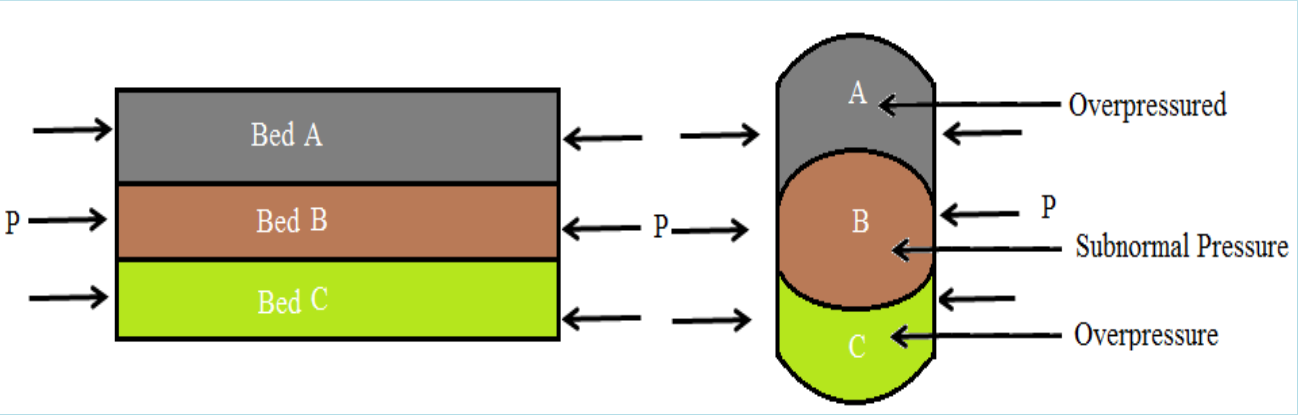


Figure 6 Foreshortening of formation beds

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

iii) Precipitation: In dry areas such as Texas, Middle East, South India etc., the water table may be located hundreds of feet below surface. This reduces the hydrostatic pressures and hence creates subnormal pressured zone in the formation.

iv) Epeirogenic Movements: A change in elevation can cause abnormal pressures in formations open to the surface laterally, but otherwise sealed. If the outcrop is raised this will cause overpressures, if lowered it will cause subnormal pressures. However, pressure changes are rarely caused by changes in elevation alone because associated erosion and deposition are also significant. Loss or gain of water saturated sediments is also important.

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

v) Depletion: A subnormally pressured zone may occur when hydrocarbons or water are produced from a capable formation in which no subsidence happens (Figure 7). This is important when drilling development wells through a reservoir where there is a production for some time. Some pressure gradients in Texas aquifers have been as low as 0.36 psi/ft.

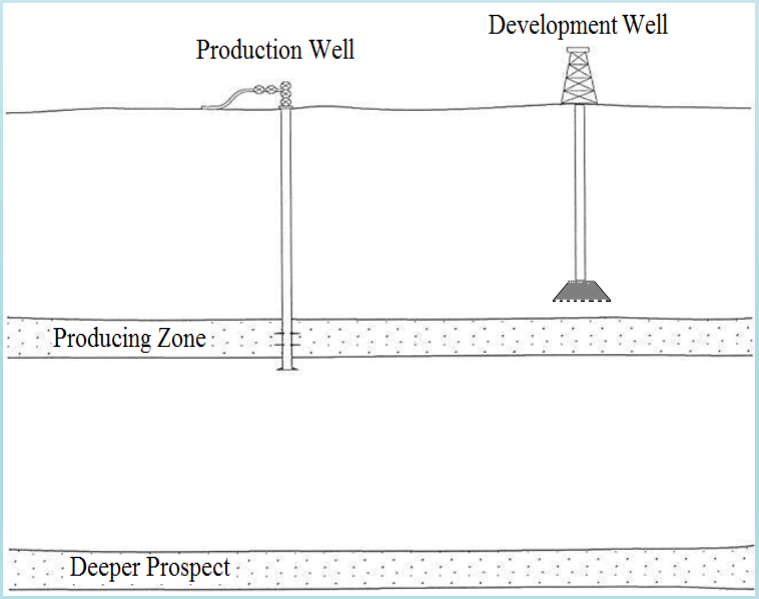


Figure 7 Production of oil or gas

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

vi) Potentiometric Surface: This mechanism refers to the structural relief of a formation and can result in both subnormal and overpressured zones. The potentiometric surface is defined by **the height to which confined water will rise in wells drilled into the same aquifer**. The potentiometric surface can therefore be thousands of feet above or below ground level (Figure 8).

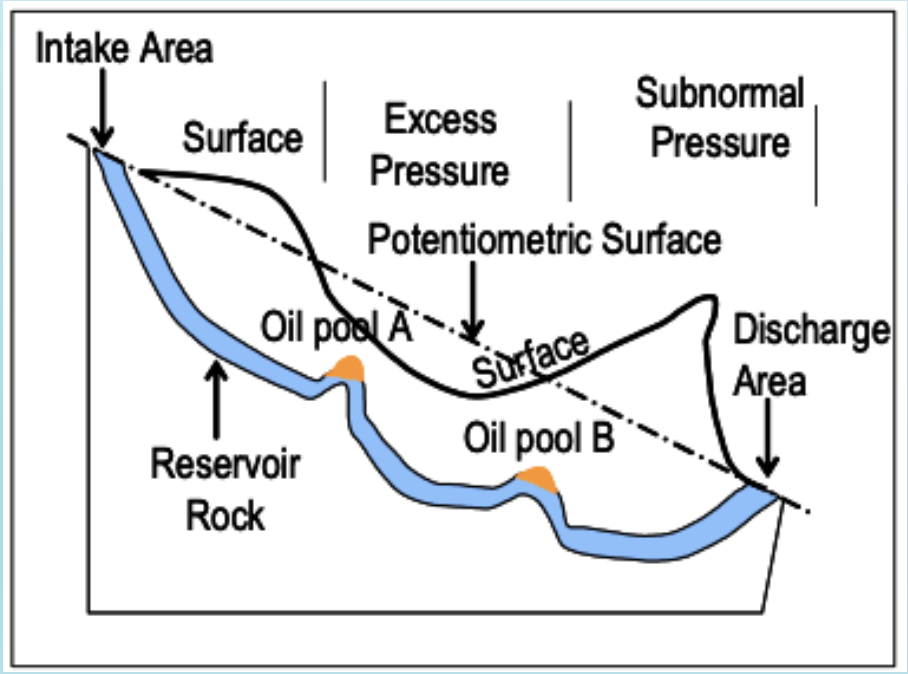


Figure 8 Potentiometric surface in connection with the ground surface

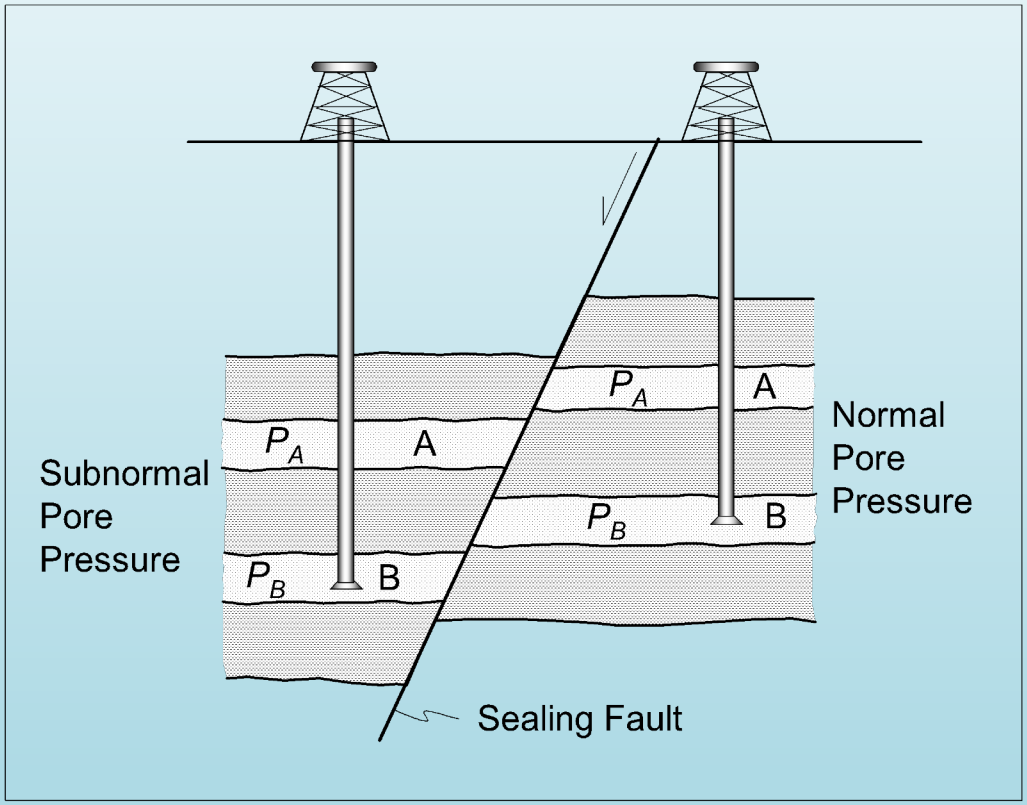
Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

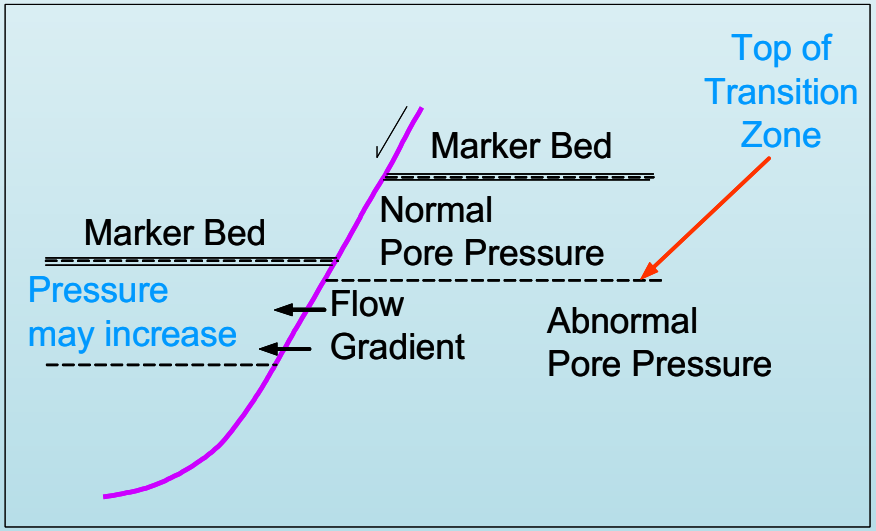
vii) Faulting: A discontinuity in a rock formation caused by fracturing of the earth's crust can create the fault. There are various causes of fault fractures such as the movement of "tectonic plates" relative to each other. In oilfield terms **a fault block is a compartment of a rock formation surrounded or partly surrounded by faults, which may have sealed in hydrocarbons separately from the rest of the formation**. When there is a sealing fault and deviates the formation zones downward, subnormal pressured zones create (Figure 9a and b). Normal faults and thrust faults are the result of various stress imbalances in the crust and superficial sediments. They are often caused by, helped by, or linked to overpressure. When moving and dilating, pressures can easily be transferred. This can result in moving fluids to a previously lower potential or bleeding pressure off, returning it back to hydrostatic. Faults are also good lateral seals.

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..



(a) Normal Faulting



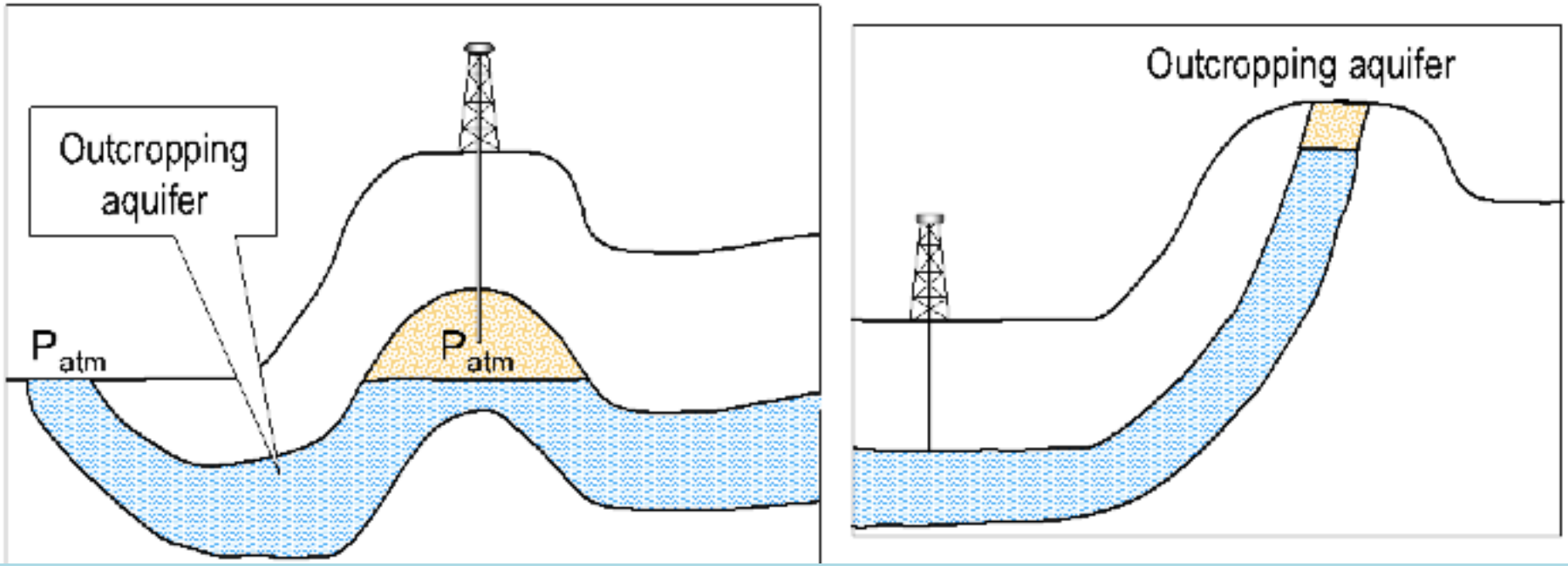
(b) Down faulting

Figure 9 Subnormal pressures due to faulting

Formation Pressure Cont..

ii. Underpressured Formation Pressure (Mechanism) Cont..

viii) Outcrop Aquifer: Outcrop can be defined as the appearance of occurrence of a rock formation at the surface whereas an **aquifer** is an underground water reservoir contained between layers of rock, sand or gravel. Figure 10 shows a portion of bedrock or other stratum protruding through the soil level, indicating a fault or some other oil-bearing formation.



a) Aquifer outcrops below rig b) Aquifer

Figure 10 Aquifer outcrops below rig

Good Luck

and

Thanks for Being with my Couse

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