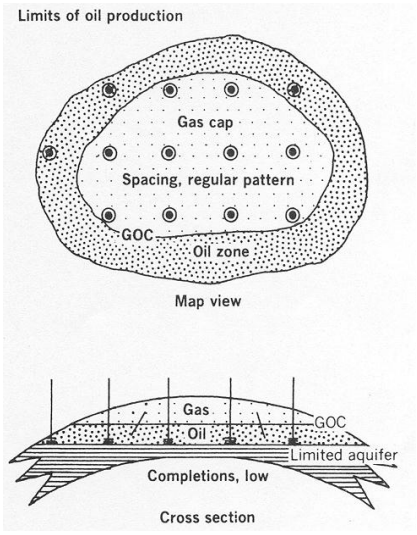
Chapter 3
Reserve Estimation



Lecture notes for PET 370

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Reserve Estimation

Volumetric oil – in – place,

$$N = \frac{7758A}{B_{oi}} \sum_{i=1}^{n} h_i \phi_i (1 - S_{wi})$$

where,

N = oil in place, stb

A = drainage area, acres

B_{oi} = initial formation volume factor,rb/stb

h_i = individual zone thickness, ft

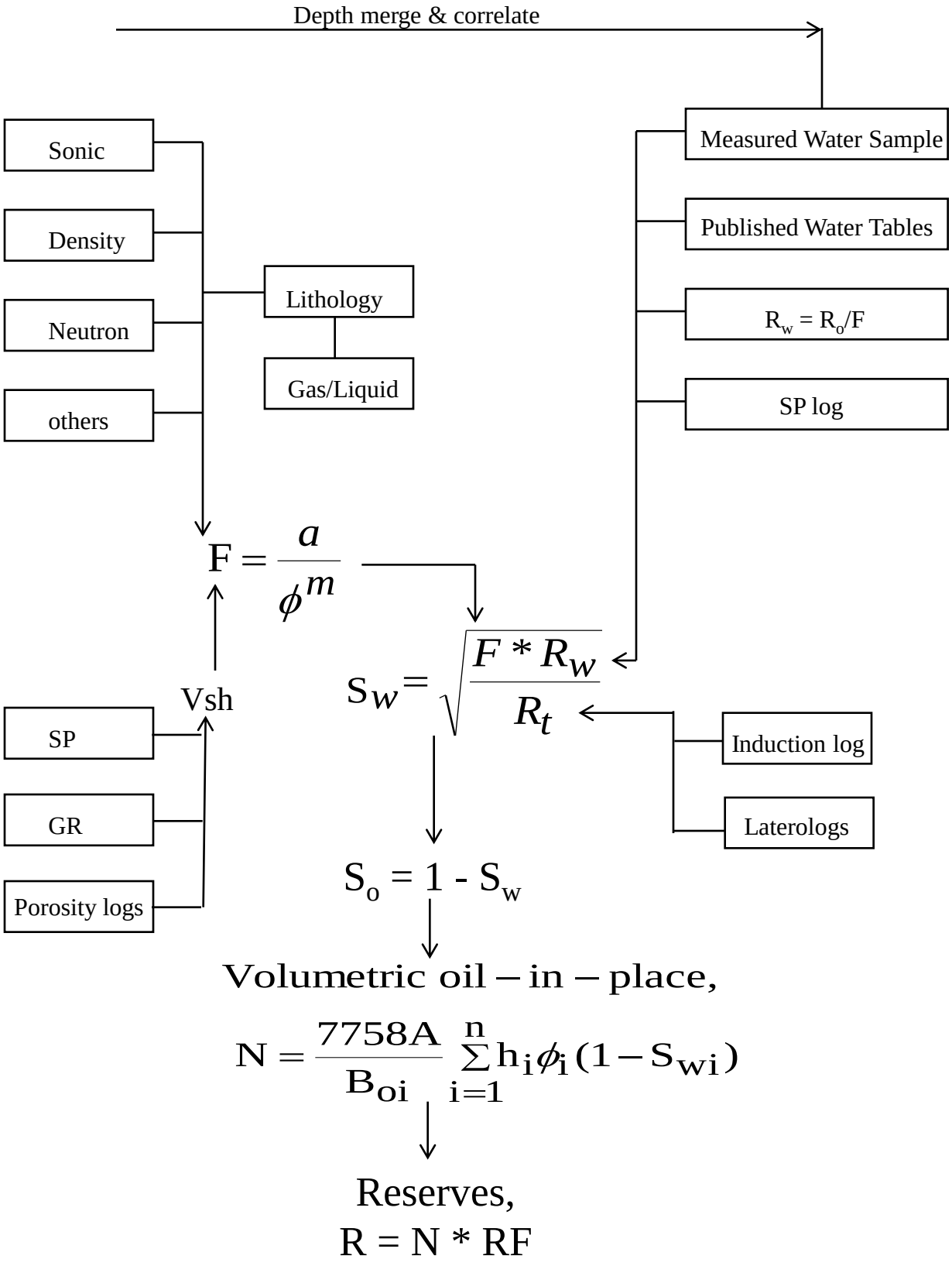
ϕ_i = porosity, fraction

S_{wi} = water saturation, fraction

Reserves are defined by:

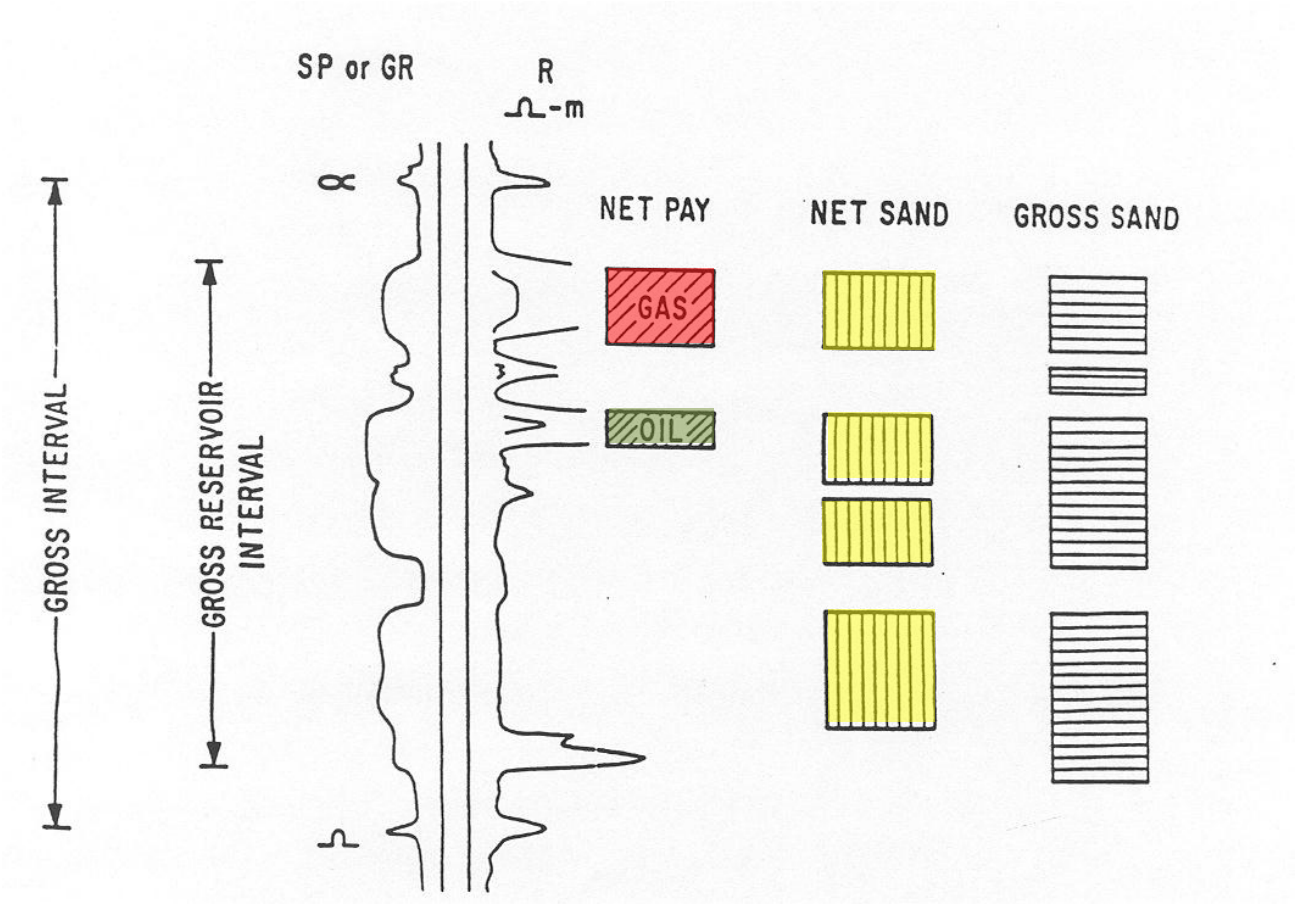
$$R = N * (E_r)$$

E_r = recovery factor



Flowchart for Well Log Interpretation

Definition of Reservoir Intervals



Reserve Estimation	Cutoff Values

1. Shale content (Vsh) – eliminate the portion of the formation which contains large quantities of shale.

   Vshcutoff ≈ 20 to 30 %

   (Note: shale plays up to 40 to 50%) **GROSS SAND**

2. Porosity – eliminate the portion of the formation which is low porosity (and low permeability) and therefore would be non-productive.

   Sandstones

   ϕcutoff ≈ 5% to 15%

   consolidated → friable, unconsolidated

   Carbonates

   ϕcutoff ≈4%

   (Note: shale plays ~ 3 to 4%) **NET SAND**

3. Water saturation – eliminate the portion of the formation which contains large volumes of water in the pore space.

   Sandstones

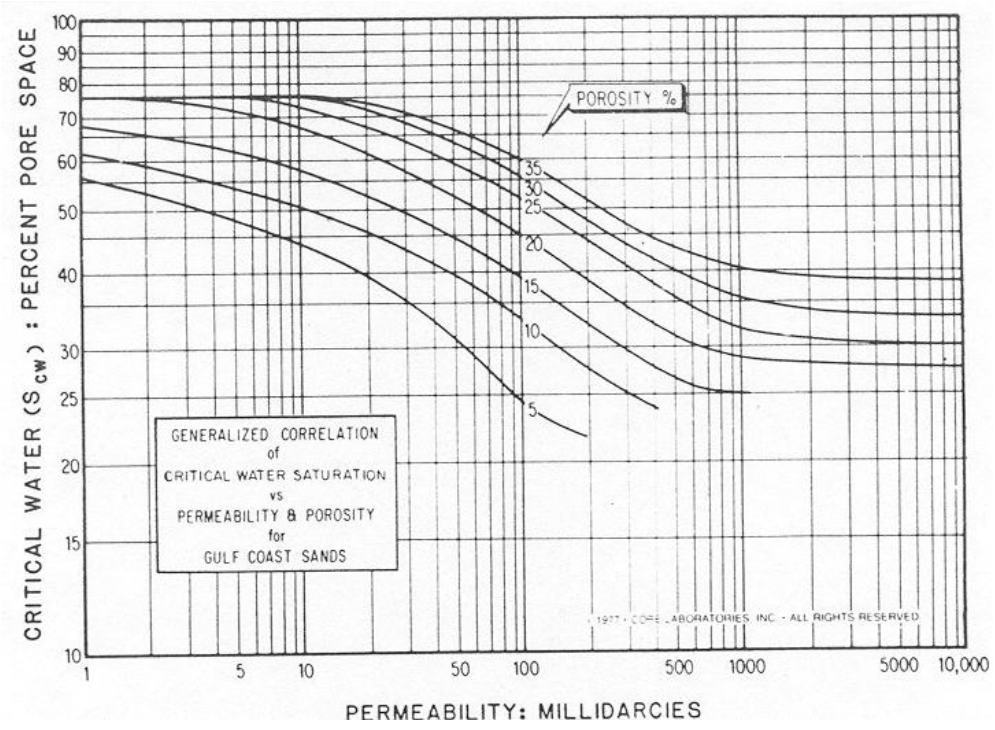
   Swcutoff ≈ 60%

   Carbonates

   Swcutoff ≈ 50%

NET PAY

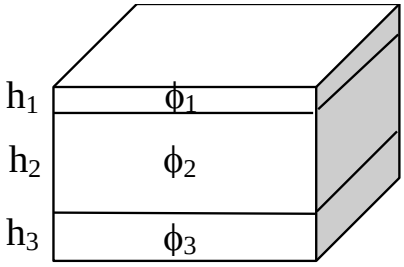
Specific Correlation



- Applicable to U.S. gulf coast sands
- Correlation between k, ϕ, and Sw
- Assumes oil/water viscosity ratio = 2.0

Porosity – thickness weighted average

$$\bar{\phi} = \frac{\sum_{i=1}^{n} \phi_i h_i}{\sum_{i=1}^{n} h_i}$$

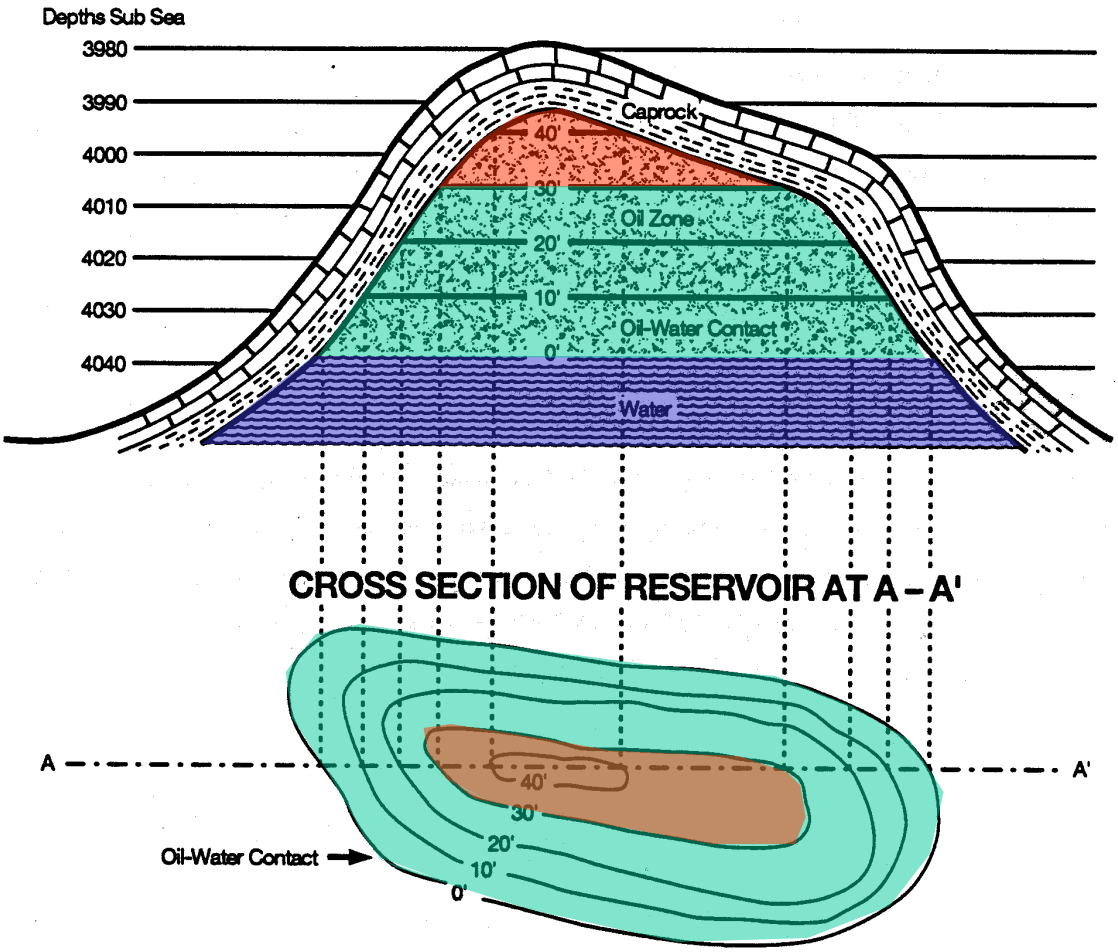


Water saturation – volume weighted average

$$\overline{S_w} = \frac{\sum_{i=1}^{n} S_{wi} \varphi_i h_i}{\sum_{i=1}^{n} \varphi_i h_i}$$

Reserve Estimation

Reservoir Volume



$$V_b = \frac{h}{3}\left(A_n + A_{n+1} + \sqrt{A_n * A_{n+1}}\right)$$

or

$$V_b = \frac{h}{2}\left(A_n + A_{n+1}\right)$$

Determined from:

1. displacement efficiency studies
2. correlations based on statistical studies of particular types of reservoir mechanisms

OIL

volumetric reservoirs

$$E_r = 1 - \frac{1 - S_w - S_g}{1 - S_w}\left(\frac{B_{oi}}{B_o}\right)$$

Total free gas saturation at abandonment by core analysis. Assumes core fluids (oil and water) are displaced by expansion of the liberated gas while removing the core to the surface…similar process to depletion.

hydraulic reservoirs

$$E_r = \frac{1 - S_w - S_{or}}{1 - S_w}$$

Estimate S_{or} from the remaining oil in the cores after flushed by mud filtrate and expansion of gas…displacement process

GAS

Volumetric Reservoirs

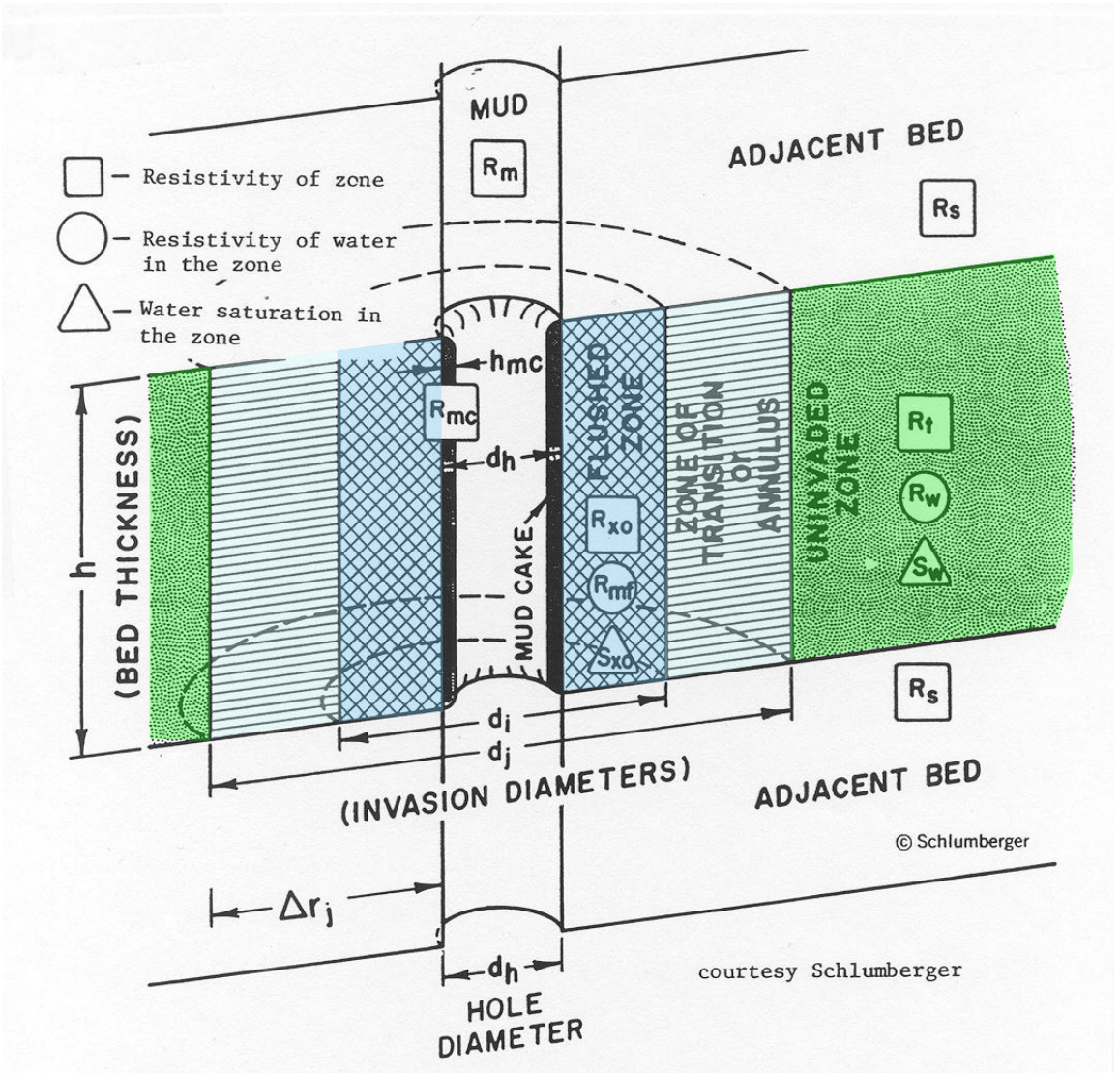
$$E_r = 1 - \left(\frac{B_{gi}}{B_{ga}} \right)$$

Hydraulic Reservoirs

$$E_r = \frac{1 - S_w - S_{gr}\left({}^{B_{gi}}\!/\!_{B_{ga}} \right)}{1 - S_w}$$

Reserve Estimation	Recovery Factor

From displacement of reservoir fluids (invasion) using well logs



From displacement of reservoir fluids (invasion) using well logs

Difference between initial oil saturation, S_{oi} and the residual oil saturation, S_{or}, that remains after the formation is invaded by water:

$$S_{om} = S_{oi} - S_{or}$$

Inferring mud filtrate invasion as an efficient displacement mechanism, then

$$S_{om} = S_{xo} - S_{w}$$

Recovery factor for water drive reservoirs,

$$\left(E_r\right)_{wd} = \frac{S_{xo} - S_w}{1 - S_w}$$

....for depletion drive, use *rule of thumb* of 1/2 of $(RF)_{wd}$

Statistical Performance

Soln Gor	Oil gravity	Sandstones maximum	Sandstones average	Sandstones minimum	Carbonates maximum	Carbonates average	Carbonates minimum
60	15	12.8	8.6	2.6	28.0	4.4	0.6
	30	21.3	15.2	8.7	32.8	9.9	2.9
	50	34.2	24.8	16.9	39.0	18.6	8.0
200	15	13.3	8.8	3.3	27.5	4.5	0.9
	30	22.2	15.2	8.4	32.3	9.8	2.6
	50	37.4	26.4	17.6	39.8	19.3	7.4
600	15	18.0	11.3	6.0	26.6	6.9	1.9
	30	24.3	15.1	8.4	30.0	9.6	2.5
	50	35.6	23.0	13.8	36.1	15.1	4.3
1000	15	-	-	-	-	-	-
	30	34.4	21.2	12.6	32.6	13.2	4.0
	50	33.7	20.2	11.6	31.8	12.0	3.1
2000	15	-	-	-	-	-	-
	30	-	-	-	-	-	-
	50	40.7	24.8	15.6	32.8	14.5	5.0

Solution Gas Drive Reservoirs (Arps, 1962)

Drive	Sandstones minimum	Sandstones average	Sandstones maximum	Carbonates minimum	Carbonates average	Carbonates maximum
Water drive	27.8	51.1	86.7	6.3	43.6	80.5
Solution gas drive without supplemental drives	9.5	21.3	46.0	15.5	17.6	20.7
Solution gas drive with supplemental drives	13.1	28.4	57.9	9.0	21.8	48.1
Gas cap drive	15.8	32.5	67.0	Combined with sandstone		
Gravity drainage	16.0	57.2	63.8	Data not available		
Gas depletion	75.0	85.0	95.0			
Gas water drive	50.0	70.0	80.0			

Recovery factor for different drive mechanisms

Chapter 11, Sec 11.4-11.7, Bassiouni, Z: Theory, Measurement, and Interpretation of Well Logs, SPE Textbook Series, Vol. 4, (1994)

Corelab, Fundamentals of Core Analysis, Houston, TX (1983), Chapter 7