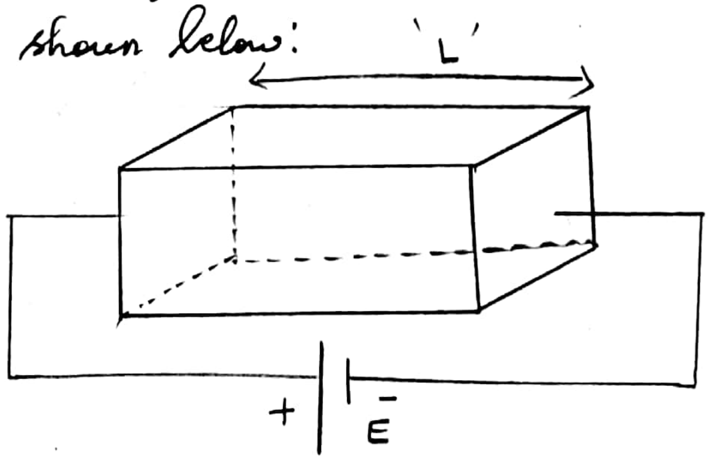
Unit-5) 23) Describe the subsurface correlation & Mapping from well log data.

Unit - 5

Formation factor, porosity, permeability, resistivity water & hydrocarbon saturation & movable oil are various formation parameters. To estimate the potential for producing oil or gas, these parameters are very useful.

Relationship between Formation factor & Resistivity:

Resistance of brine in a container of length 'L' and cross section area 'A' to flow of electricity is measured by applying a voltage 'E' in volts across liquid to record the amount of current 'I' in amperes that will be flowing as shown below:



According to Ohm's law, resistence r_w is equal to

$$r_w = \frac{E}{I_w}$$

Resistivity of Brine, $R_w = r_w \cdot \frac{A}{L}$

$$R_w = \frac{E}{I_w} \cdot \frac{A}{L} \quad \text{--- (1)}$$

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Now consider a block of porous rock (clean sand) of same dimension A & L and 100% saturated with same brine. On Applying the same Voltage 'E' across block of sand a current I_o will flow.

Resistivity of this porous rock sample is R_o.

$$R_o = r_o \frac{A}{L} = \frac{E}{I_o} \cdot \frac{A}{L} \quad \text{—(2)}$$

Dividing (2) by (1)

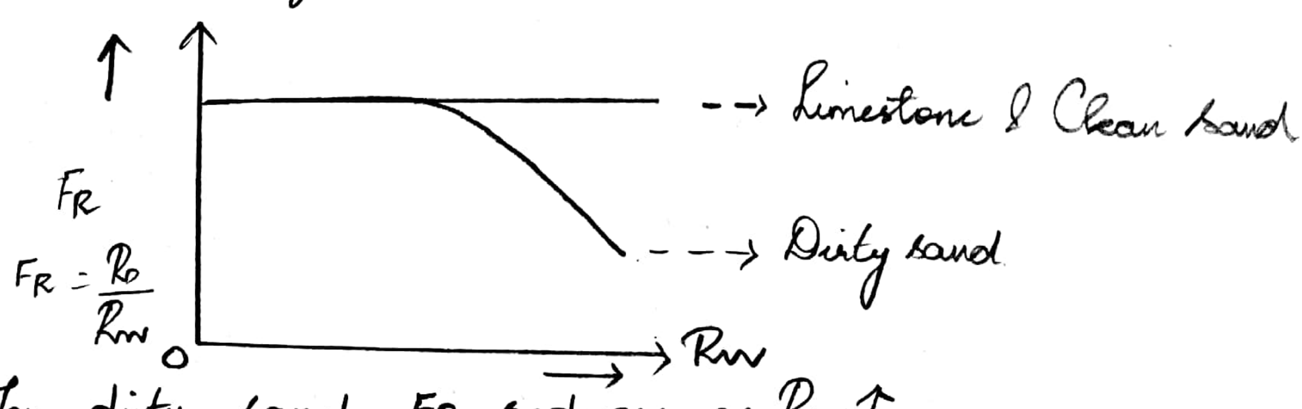
$$\frac{R_o}{R_W} = \frac{I_W}{I_o}$$

Archie defined this ratio as formation resistivity factor

$$F_R = \frac{R_o}{R_W}.$$

For a given 'E' value, $I_W > I_o$ and so $R_o > R_W$. F_R will always be greater than Unity.

This Formation factor Vs R_W can be mapped as:



For dirty sand, F_R reduces as $R_W \uparrow$

24) What are reservoir parameters? How is porosity & permeability determined using well log data?

Porosity, Permeability, Water Saturation, Oil Saturation are all reservoir parameters which determines the potential of a formation or a reservoir.

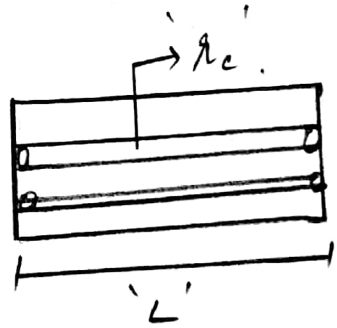
Relationship between Formation factor & Porosity:

Assuming the saturated porous rock sample containing an ideal porous material of n straight cylindrical capillaries.

Relationship between total cross sectional area of Container A and cross sectional area of 'n' capillary tubes of length 'L' is $A_0 = n\pi r_c^2$ (r_c - Capillary tube radius)

$A_n = \phi A$ (ϕ - fractional porosity)

$$R_{wc} = E/I_{wc} \times \frac{A_n}{L}$$



$$F_R = R_o/R_{wc}$$

Since $R_o = \frac{E}{I_o} \cdot \frac{A}{L}$

$$F_R = \frac{R_o}{R_{wc}} = \frac{\frac{E}{I_o} \times \frac{A}{L}}{\frac{E}{I_{wc}} \times \frac{A_n}{L}} = \frac{I_{wc}}{I_w} \times \frac{A}{A_n}$$

$$F_R = \frac{I_{wc}}{I_{wo}} \times \frac{1}{\phi}$$

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As the system is supposed to be a porous rock sample.

$$F_R = 1/\phi$$

Porosity & Permeability Relationship.

When $\phi = 0$, $k = 0$, when $\phi = 100\%$, K = infinite.

$$Q = \frac{kA\Delta P}{\mu L} = \frac{n\pi r^4 \Delta P}{8\mu L} \rightarrow (1)$$

↳ (Poiseuille eq.)

Solving for k, we get

$$k = \frac{n\pi r^4}{8A} \rightarrow (2)$$

ϕ = Pore volume / Bulk Volume.

$$\phi = n\pi r^2 L / AL \rightarrow (3)$$

$$\boxed{k = \frac{\phi r^2}{8}} \rightarrow \text{Substituting from (2) \& (3)}$$

↳ (4)

Specific Surface area

S_p = Surface Area / Pore Volume

$$= n 2\pi r L / n\pi r^2 L$$

$$r = 2/S_p \rightarrow (5)$$

Combining (4) & (5)

$$k = \frac{1}{2}\frac{\phi}{S_p^2}$$

1/2 can be substituted by $1/k$, Kozeny Constant

then $$k = \frac{\phi}{k_z S_p^2}$$

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25) and 27) Discuss the relationship of few reservoir parameters from well log Data.

Correlation between F_R and Tortuosity:

$$\tau = \left(\frac{L_a}{L}\right)^2$$

τ - Tortuosity factor

L_a - Actual length of path

L - Torturous path.

$$R_{wc} = \frac{E}{I_{wc}} \times \frac{\phi A}{L_a}$$

$$A_n = \phi A$$

$$F_R = \frac{R_o}{R_{wc}} = \frac{\frac{E}{I_o} \times \frac{A}{L}}{\frac{E}{I_{wc}} \times \frac{\phi A}{L_a}} \quad (\text{For } I_o = I_{wc})$$

$$F_R = \frac{1}{\phi}\left(\frac{L_a}{L}\right) \quad \left(\because \frac{L_a}{L} = \sqrt{\tau}\right)$$

$$F_R = \frac{1}{\phi}\sqrt{\tau}$$

Correlation between F_R & Cementation:

$$F_R = a/\phi^m \Rightarrow F_R = \frac{1}{\phi^m} \times a \quad (\text{Archie's Equation})$$

$$F_R = \frac{0.62}{\phi^{2.15}} \text{ or } \frac{0.81}{\phi^2} \quad (\text{Humble's Equation})$$

m - Cementation Constant.

Correlation between F_R & Permeability.

$$k \propto \frac{d_{gr}}{F_R^{0.6\sigma 2}}$$

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d_{gr} - geometric mean grain diameter.
σ_2 - S.D of log grain size distribution

Correlation between F_R & Water Saturation:

$$S_w = \left(\frac{R_o}{R_t}\right)^{1/n} = \left(\frac{F_R . R_w}{R_t}\right)^{1/n}$$

$$F_R = a/\phi^m$$

$$S_w = \left(\frac{a}{\phi^m} \times \frac{R_w}{R_t}\right)^{1/n}$$

n is Saturation exponent.

$$S_w = \left(\frac{R_o}{R_t}\right)^{1/n}$$

$$n = \frac{\log IR_1 - \log IR_2}{\log S_{w2} - \log S_{w1}}$$

Movable Oil Saturation:

$$S_{om} = 1 - S_{wc} - S_{or}$$

S_{om} is movable oil Saturation.

S_{wc} is connate water Saturation

S_{or} is residual Oil Saturation

Residual Oil Saturation:

$$S_{hr} = 1 - S_{xo}$$

S_{hr} is Residual hydrocarbon saturation

S_{xo} is Invaded zone - water Saturation.

Recovery factor, R_F = S_{hr} / S_{hy} (S_{hy} - Total hydrocarbon saturation)

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2) How is formation factor calculated from well log Data.
It is an excellent parameter for the detection of hydrocarbon zones. A rock that contains oil & gas will have a higher resistivity than same rock completely saturated with formation water. Greater the connate water saturation, lower is formation resistivity.

When a rock sample is saturated with salt water whose resistivity is R_w, a current will circulate through electric field and a corresponding potential drop is observed across sample. Resistence of rock when calculated with Ohm's law will be

$$r_0 = R_0 (L/A)$$

R_0 is resistivity of water.

$$r_w = R_w \left(\frac{L_e}{A_e}\right) \quad (e - \text{electrodes})$$

$$A_e = \frac{\phi A L}{L_e}$$

ϕAL - Volume of water in rock sample

L - Actual length of path

L_e - Length of torturous path

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Ae - Cross sectional area of equivalent water Volume

ro - resistance of Coreplug saturated with water

rw - resistance of equivalent water Volume.

$$r_w = R_w \frac{L_e}{A_e} \Rightarrow R_w = \frac{L_e^2}{\phi A L} \quad \left(\because A_c = \frac{\phi A L}{L_e} \right)$$

Because $r_o = r_w$

$$r_o = r_w = R_w \frac{L_e^2}{\phi A L}$$

$$R_w \frac{L_e^2}{\phi A L} = R_o \left(\frac{L}{A} \right)$$

$$R_o = R_w \left(\frac{L_e^2}{\phi A L} \right) \times \left(\frac{A}{L} \right)$$

$$R_o = F R_w$$

$$F = \left(\frac{L_e}{L} \right)^2 \left(\frac{1}{\phi} \right) = \frac{\tau^2}{\phi}$$

$$F = \left(\frac{L_e}{L} \right)^2 \frac{1}{\phi}$$

$$F = \frac{\tau^2}{\phi} \quad \left(\tau = \frac{L_e}{L} \Rightarrow \text{Tortuosity factor} \right)$$

F = Formation resistivity factor → Dimensionless

This is an important factor in electric log interpretation

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