ESN-423 Well Logging

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GPT, 4th Year

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Tutorial-3

Necessary detail of an exploratory well are as follows:

47.5 ft	Derrick Floor
48 ft	KB
-6689 ft	GL
6641.5 ft	Thickness of water column
0.0068 degF/ft	Temperature Gradient
1.00 g/cc	Average sea water density
2.300 g/cc	Average overburden density
2.65 g/cc	Sandstone matrix density
1.00 g/cc	RhoFl
55.6 us/ft	DTma
189 us/ft	DTfl

1. Calculate Vsh using three different correlations (including the linear) and plot Vsh versus GR

Solution: (i) Linear Vsh calculation

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}}$$

where:
IGR = gamma ray index
GRlog = gamma ray reading of formation
GRmin = 68, minimum gamma ray (clean sand or carbonate)
GRmax = 110, maximum gamma ray (shale)
GRmin/GRsand and GRmax/GRshale are estimated from manual consistent picking.

The nonlinear responses are:
(ii) Larionov (1969) for Tertiary rocks

$$V_{sh} = 0.083\left(2^{3.7 \cdot I_{GR}} - 1\right)$$

(iii) Steiber (1970):

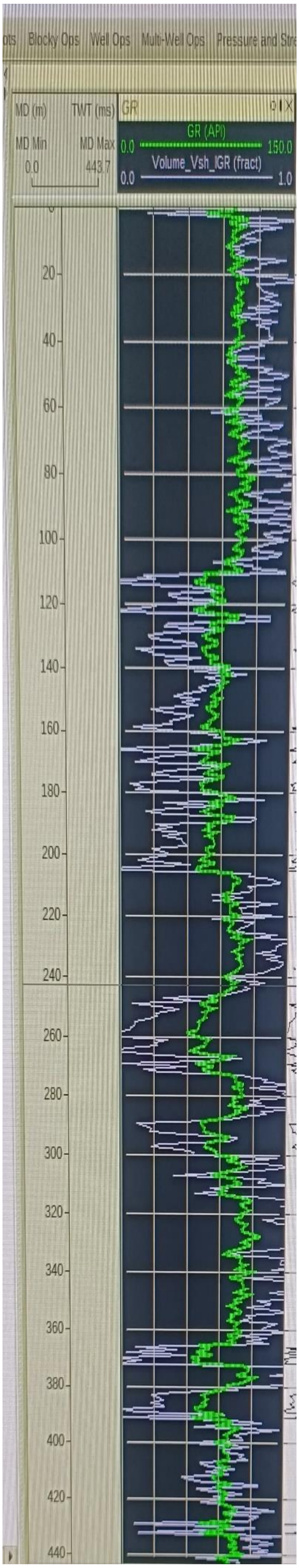
$$V_{sh} = \frac{I_{GR}}{3 - 2 \times I_{GR}}$$

Plots of Vsh vs GR for different Vsh calculations are plotted below.

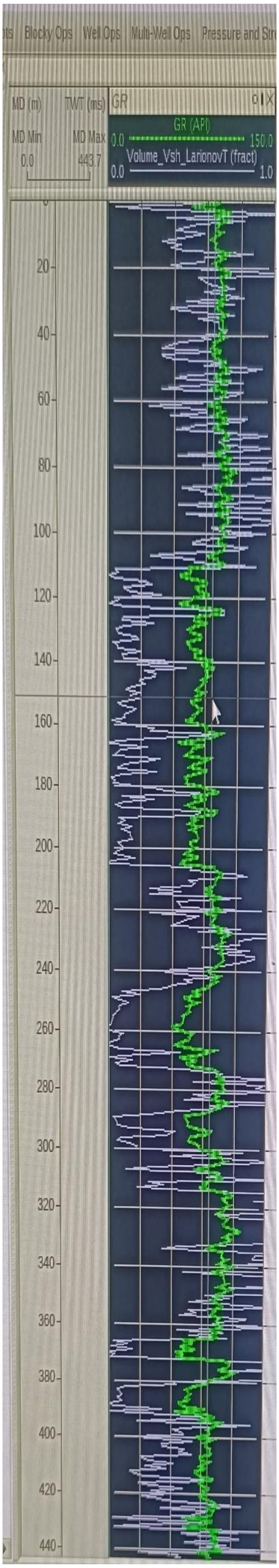
Observation:

- The nonlinear responses like Larionov and Steiber are showing the more Optimism, which is Lower Calculated Shale Volumes or in other words more calculated Clean Sands volumes.
- Also nonlinear are more consistent.
- All Vsh calculation are positively correlated with GR showing good trend.

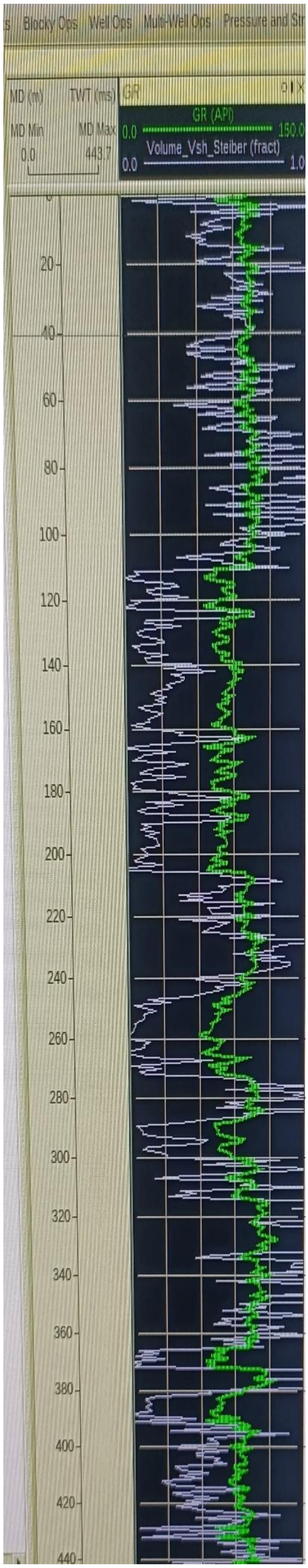
i) GR vs Vsh_IGR



ii) GR vs Vsh_Larionov



iii) GR vs Vsh_Steiber



2. Calculate porosity using Density and DT. Plot the two porosities versus Vsh.

Solution:

i). Porosity calculated from Density log:-

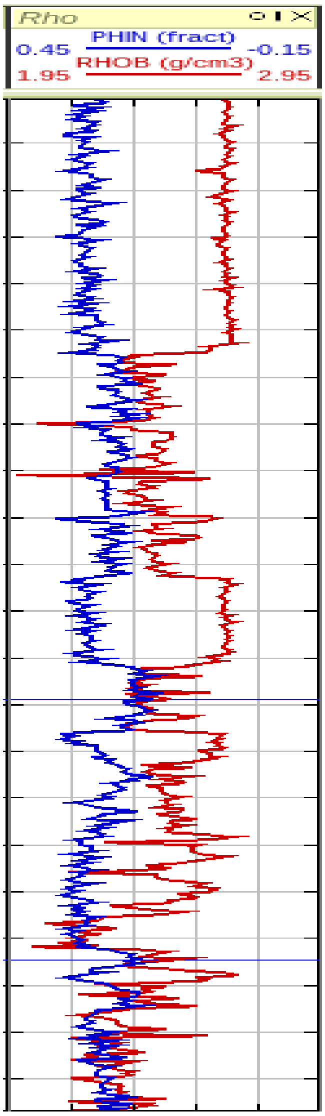
By observing the NPHI and Density Log, I estimated the pma = 2.86, which is the case for Dolomite and pf=1.

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Where,

ρ_{ma} = Matrix Density = 2.86 for Dolomite
= 2.71 for Limestone
= 2.65 for Sandstone

Observation: NPHI is showing very high value of porosity for Shaly formations unlike the Porosity calculated from density log indicating that Neutron log is overestimating the Porosity values due to presence of Bound water in shales.

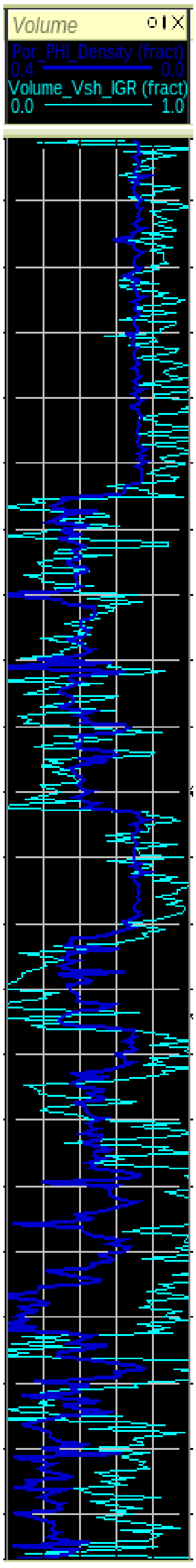


Porosity calculated from both Density log and DT log gives good match with each other in Sand regions and values validate with our Dolomite formation estimation and also matches with the near true porosity value achieved after convergence in 3 Part.

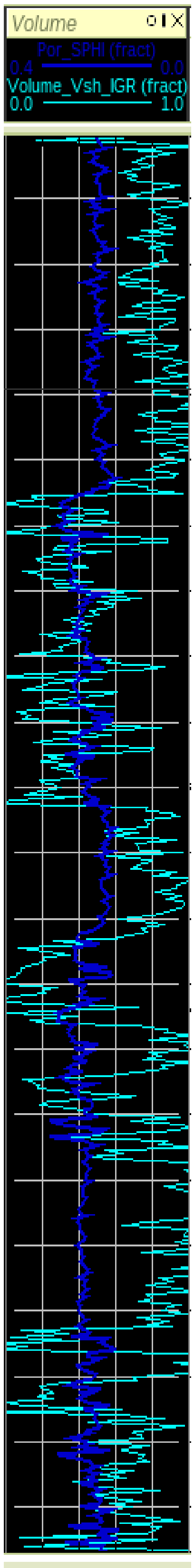
ii). Porosity calculated from DT Log: -

$$SPHI = \phi_S = \frac{DT - DTMa}{DTFl - DTMa}$$

I) Vsh vs PHI_D



II) Vsh vs SPHI



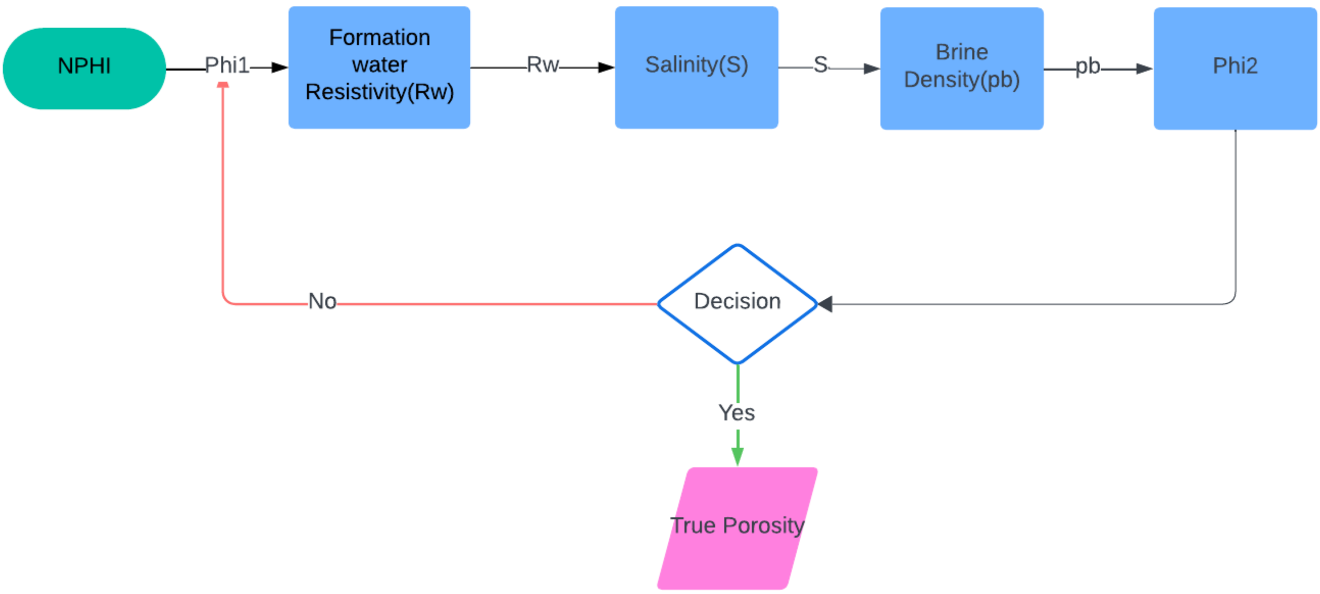
3. Iterate for porosity and fluid density in every sand and then Calculate saturation using Archie's equation. Use a = 1, m = 2, n = 2. Use the Tutorial Guidance provided and the Technical Paper by Batzle and Wang (1992).

Solution: By analyzing the overlapping of Neutron-Density Plot and low GR values, the following are the provided Log values of parameters for Water-Bearing Formations marked at five different depths.

depth (m)	P(in Mpa)	RHOB	P(in psi)	Temp(F)	Depth(ft)	NPHI	Rt	Rw
2279	28.32697	2.34	4111.316	149.7512	7475.12	0.25	23.11	1.444375
2413	29.99253	2.38	4353.052	154.1464	7914.64	0.21	10.2	0.44982
2550	31.69538	2.38	4600.2	158.64	8364	0.24	9.4	0.54144
2425	30.14168	2.47	4374.7	154.54	7954	0.17	15.52	0.448528
2537	31.53379	2.53	4576.748	158.2136	8321.36	0.2	6.11	0.2444

Temperature is calculated by using avg T Gradient=0.01 deg F/ft and Surface Temperature=75 deg F.
Pressure is calculated by using avg P Gradient=0.55 psi/ft and converted into MPa.

Methodology:



Where,

- NPHI is Neutron Log values
- Rw is Formation water Resistivity
- S is the salinity in PPM
- pw is water density at formation depth
- pB is Brine Density
- Phi1 is the porosity value in the start of current iteration within a loop.
- Phi1=NPHI for the first iteration.
- Phi2 is the new porosity value calculated in the end of current iteration within a loop.
- Decision box contains the convergence criterion.
- Convergence Criteria: |Phi2-Phi1|<0.001
- True Porosity is the final porosity value after convergence is achieved.

As we have marked the water-bearing formation therefore, Sw=1(water saturation is assumed to be 1) which reframes the Archie's Equation: Sw^n=(a*Rw)/((phi^m)*Rt) to Rw=(phi^m)*Rt.

Steps performed to calculate Phi2 from Phi1 are following:
Step-1: calculate Rw from Rw=((phi1)^m)* Rt.
Step-2: calculate Salinity(S) in PPM from:

$$NaCl = 10^{\wedge}\left[\frac{1}{0.955}\left(\log_{10}(3647.5) - \log_{10}\left(R_w\left[\frac{T+6.77}{81.77}\right]-0.0123\right)\right)\right]$$

Step-3: calculate pw from:

$$\rho_W = 1 + 1 \times 10^{-6}(-80T - 3.3T^2 + 0.00175T^3 + 489P - 2TP + 0.016T^2P - 1.3 \times 10^{-5}T^3P - 0.333P^2 - 0.002TP^2) \qquad (27a)$$

Step-4: calculate pb from:

$$\rho_B = \rho_W + S\{0.668 + 0.44S + 1 \times 10^{-6}[300P - 2400PS + T(80 + 3T - 3300S - 13P + 47PS)]\}, \qquad (27b)$$

Here S is Salinity(S)/10^6.
Step-5: calculate Phi2 using pB(Brine Density) as pf(fluid density) from:

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Now make Phi1=Phi2 and repeat until the covergence criteria is achieved.

Below is the Matlab code to calculate Final Porosity from the method demonstrated in Flow chart:
Matlab Code:

```
clc
clear all
close all
format long
% Below are the values of parameters at depths where the Formation is Water Bearing
% These Depths are marked by analysing the Neutron-Density plot \
Depth=[2279,2413,2425,2537,2550];  % depths in m
NPHI=[0.2500,0.2100,0.1700,0.2000,0.2400];  % Neutron Porosity Log value
Rt=[23.110,10.200,15.52,6.11,9.400];   % LLD Log values i.e. True Resistivity of Formation
Temp=[149.7512,154.1464,154.54,158.2136,158.6400];  % Temperature in deg F
Press=[28.32697,29.99253,30.14168,31.53379,31.69538];  % Pressure computed from avg Pressure Gradient in MPa
density=[2.34,2.38,2.47,2.53,2.38];   % Density in gm/cc
m=2;   % Cementation factor taken m=2 because Tf < 80 deg C
Sal=[];
pw=[];
pB=[];
for d=1:5
  PHI=NPHI(d);
  R=Rt(d);  % Resistivity
  T=Temp(d); % Temperature
  P=Press(d); % Pressure
  D=density(d); % Density
```

```
  PHIN=1;
  PHIO=NPHI(d);
  %tic
  for i=1:1e16
    if(abs(PHIO-PHIN)>=0.001) % Convergence criterion upto 3rd decimal place
    Rw=(PHI^m)*R; % assuming Sw=1
    PHIO=PHI;  % storing previous porosity value
    Sal(d)=(10^(1.0471*(log10(3647.5)-log10(Rw*((T+6.77)/81.77)-0.0123))))/(1e6);
    pw(d)=(1+(1e-6)*(-80*T-3.3*(T^2)+0.00175*(T^3)+489*P-2*T*P+0.016*(T^2)*P-1.3*(1e-5)*(T^3)*P-0.333*(P^2)-
0.002*T*(P^2)));
    pB(d)=(pw(d)+Sal(d)*(0.668+0.44*Sal(d)+(1e-6)*(300*P-2400*P*Sal(d)+T*(80+3*T-3300*Sal(d)-13*P+47*P*Sal(d)))));
    PHIN=(2.86-D)/(2.86-pB(d));  % By analysis, pg/pma = 2.86 is estimated, Dolomite Formation
    PHI=PHIN;
    else
    fprintf('Number of iterations for Porosity Convergence at %d depth(in m) is %d .\n',Depth(d),i);
    break;
    end
  end
  %toc
  fprintf('Final Porosity computed for this depth is %f.\n',PHIN);   % New Porosity
end
```

Output of the Code:

```
Command Window
Number of iterations for Porosity Convergence at 2279 depth(in m) is 2 .
Final Porosity computed for this depth is 0.270100.
Number of iterations for Porosity Convergence at 2413 depth(in m) is 2 .
Final Porosity computed for this depth is 0.249156.
Number of iterations for Porosity Convergence at 2425 depth(in m) is 2 .
Final Porosity computed for this depth is 0.202407.
Number of iterations for Porosity Convergence at 2537 depth(in m) is 2 .
Final Porosity computed for this depth is 0.171765.
Number of iterations for Porosity Convergence at 2550 depth(in m) is 2 .
Final Porosity computed for this depth is 0.248751.
fx >>
```

Observation:

Depth(in ft)	Rt	RHOB	NPHI	Final Porosity
7475.12	23.11	2.34	0.25	0.2701
7914.64	10.2	2.38	0.21	0.249156
7954	15.52	2.47	0.17	0.202407
8321	6.11	2.53	0.2	0.171765
8364	9.4	2.38	0.24	0.248751

- Final Porosity value from the iterations is higher than the NPHI values indicating the presence of complex pore systems of carbonate rocks other than the primary porosity systems.
- From Neutron-Density analysis and considering the general behaviour of Neutron Log values for carbonates Formation (i.e. NPHI is slightly lesser than True porosity), I estimated that the Formation is Dolomite (pma/pg=2.86gm/cc) which showed a good match with new porosity value: -
  RHOB or pb=(phi*pB+(1-phi)*pg)
  <u>(0.2701)*1+(0.7299)*2.86=2.357614 ≈ 2.34=RHOB or pb</u>

- Working of Method: - we are trying to iterate for true porosity which satisfies the true formation Resistivity (Rt), Bulk Density (pb) and Grain density(pg/pma).