UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE : **PEB2044/PFB2024 - WELL LOGGING AND FORMATION EVALUATION**

DATE : **8 AUGUST 2024 (THURSDAY)**

TIME : **9:00 AM - 12:00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.
6. **Distribute the necessary appendix page separately and tie it with the answer booklet.**

Note :

i. There are **FIFTEEN (15)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. A core plug contains oil and water. The density of the oil is 0.80 g/cc, and the density of brine is 1.05 g/cc. The core plug has a diameter of 2.54 cm and a length of 7.62 cm. The sandstone core has an oil saturation of 0.15. The saturated core plug has a mass of 92.836 g. The plug is quartz-dominated. After complete removal of oil and water, the core plug was dried. The dried core plug was then subjected to compression, resulting in a 1.25 cc decrease in pore volume.

i. Determine the porosity of the saturated core plug.

[5 marks]

ii. Calculate the porosity and density of the dried core plug before the core plug was subjected to compression.

[10 marks]

iii. Estimate the grain volume and the density of the compressed dried core plug.

[10 marks]

b. Show that the average density of fluids can be expressed as

$$\rho_f = \rho_o S_o + \rho_g S_g + \rho_w S_w$$

[5 marks]

2. a. Describe the following terms with an aid of diagram:

i. Liquid junction potential.

[3 marks]

ii. Membrane potential.

[3 marks]

iii. Static spontaneous potential.

[3 marks]

b. The formation water sample was taken, and the chemical analysis was determined to have the following properties: 600 ppm Ca^{2+}, 1,450 ppm SO_4^{2-} and 50,000 ppm NaCl at 100°F while formation temperature is 200°F. The R_{mf} is 0.5 Ω.m at 100°F.

i. Determine the formation water resistivity value based on the information given above.

[3 marks]

ii. Supposed SSP value is given as -70 mV, determine the formation water resistivity value.

[4 marks]

iii. Compare your answers in **part (b)(i)** and **(b)(ii)**, justify if both values are similar or different.

[3 marks]

c. **TABLE Q2** illustrates logging data in a well with formation resistivity 12.5 Ω.m at reservoir temperature 160°F in a gas reservoir.

TABLE Q2: Logging Data

Depth Interval (ft)	Density, ρ (g/cc)	Sonic log, Δt (μsec/ft)	Neutron, ϕ_N (v/v)	Resistivity, R_t (Ω.m)
4950 - 5000	2.355	81	0.16	32
5000 - 5050	2.365	80	0.15	30
5050 - 5100	2.465	68	0.09	4.5

i. Using M-N crossplot, determine the lithology for each depth interval.

[6 marks]

ii. Determine hydrocarbon saturation value of interval 5050 – 5100 ft. State all your assumptions.

[5 marks]

3. a. A well log suite containing a few parameters is shown in **FIGURE Q3.** The bit size is constant throughout the whole interval, which is 8.5 inches.

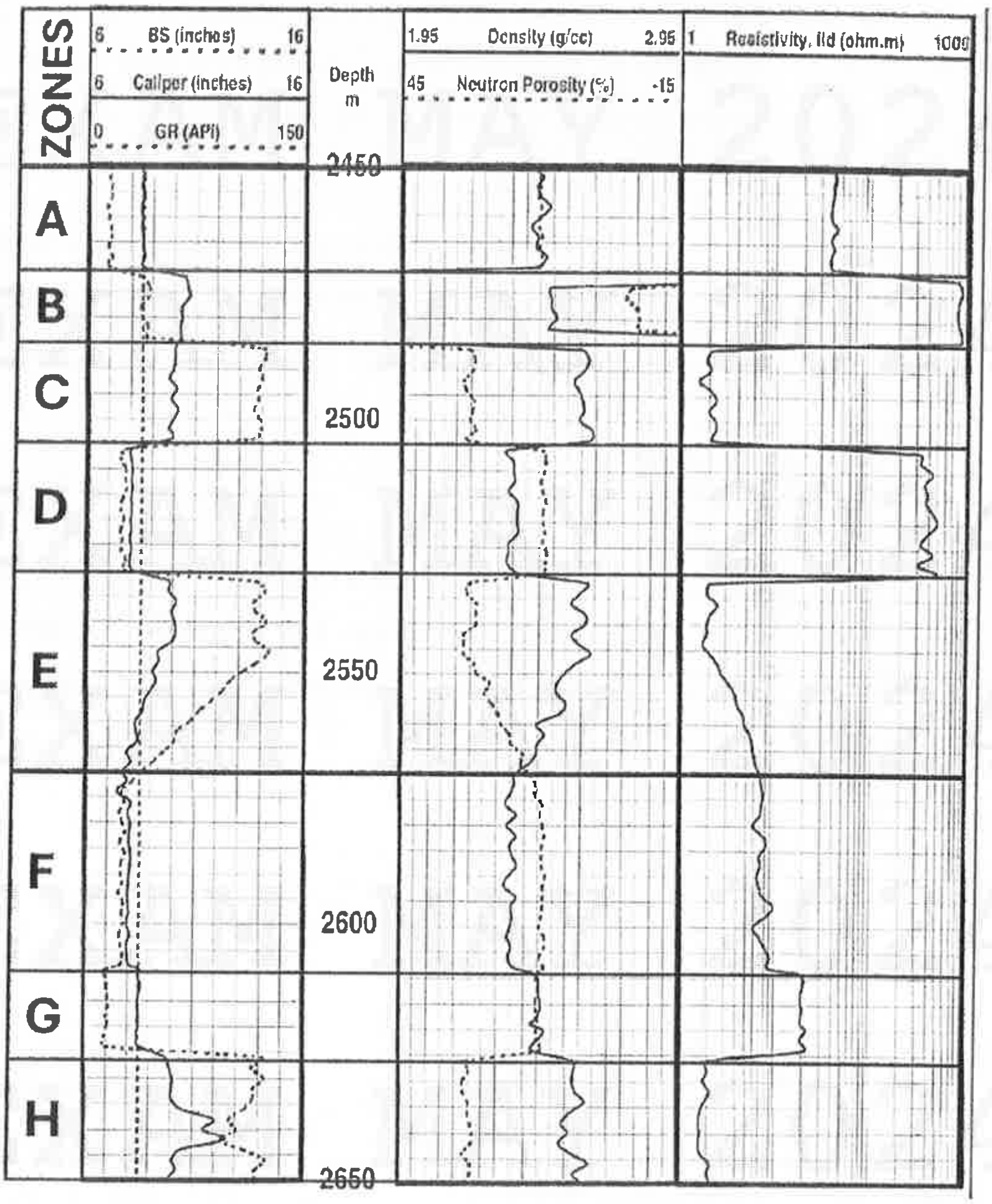


FIGURE Q3: Well Log Suite

i. Calculate volume of shale for zones A and B using linear equation.

[3 marks]

ii. Using appropriate density-neutron crossplot, justify whether zones A, D and F are similar lithology with similar porosity values.

[7 marks]

b. A neutron log and a density log measure the response of subsurface formations to different physical properties. The neutron log measures the response of formations to a neutron source that emits high-energy neutrons, while the density log measures the response to variations in formation density.

i. Explain the relationship between hydrogen content and porosity and discuss how neutron logs can be used to determine the porosity of a formation.

[5 marks]

ii. Explain the relationship between rock density and the degree of gamma-ray attenuation and discuss how density logs can be utilized to determine the porosity of a formation.

[5 marks]

4. A segment of a wireline log from Well-Y is shown in **FIGURE Q4**.

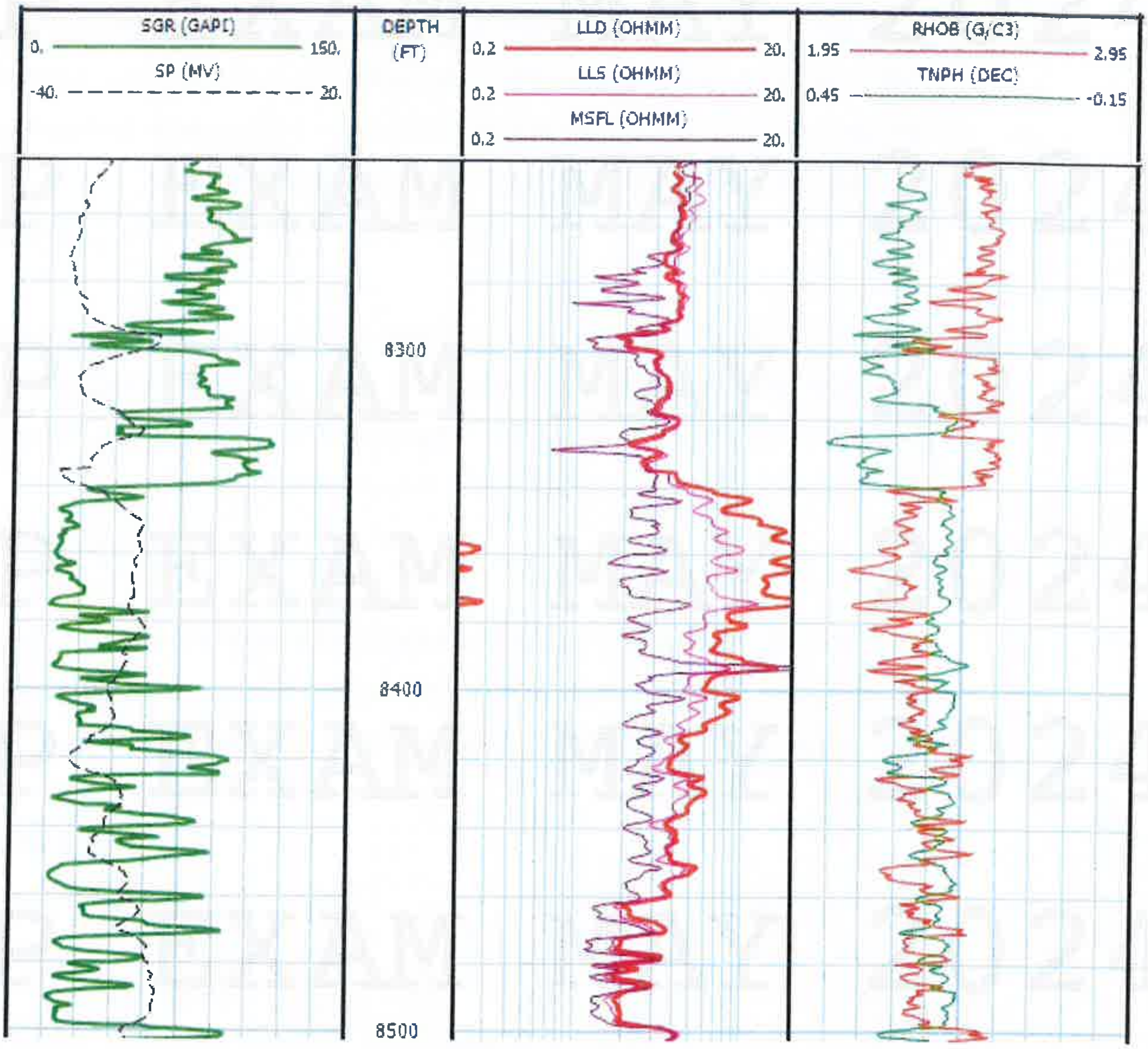


FIGURE Q4 : A segment of a wireline log from Well-Y

Based on the wireline log shown in **FIGURE Q4**,

a. Identify the depth interval(s) and describe the layers in the reservoir that are most likely shale layers. The description must include the response characteristics, such as gamma-ray, resistivity, bulk density, and neutron porosity measurements that indicate the presence of shale.

[7 marks]

b. Identify the depth interval(s) and describe the layers in the reservoir that are most likely to contain hydrocarbons. The description must include the type of hydrocarbon fluid, the response characteristics that indicate the presence of hydrocarbons within the identified layers.

[7 marks]

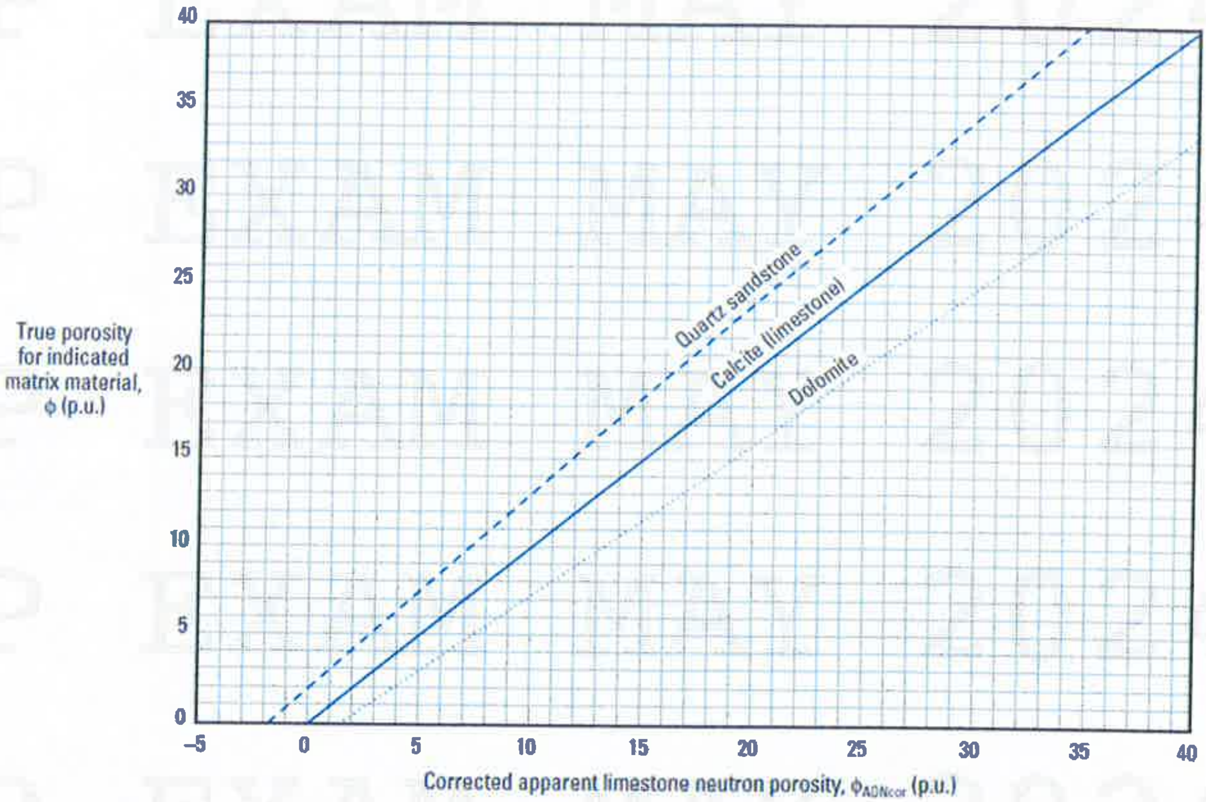
c. Estimate the depth of the oil-water contact and describe the layers in the reservoir that are most likely to be aquifers. The description must include the response characteristics that indicate the identified layers as aquifers.

[6 marks]

- END OF PAPER -

APPENDIX 1

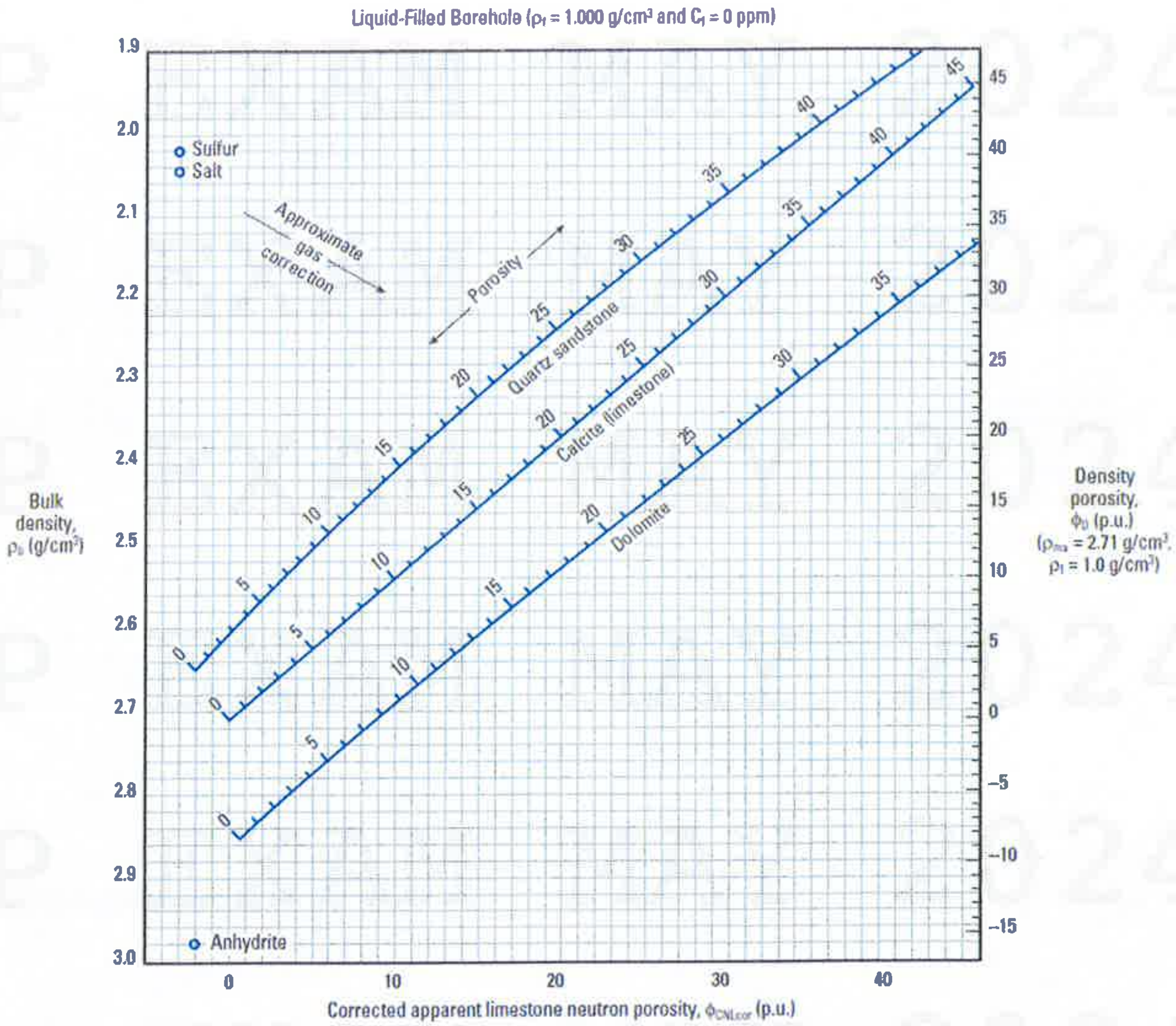
Correction chart for obtaining porosity values for lithologies other than limestone.



Credit to Schlumberger

APPENDIX 2

Neutron Porosity and Bulk Density Measurement Combination, $\rho_f = 1.000$ g/cc



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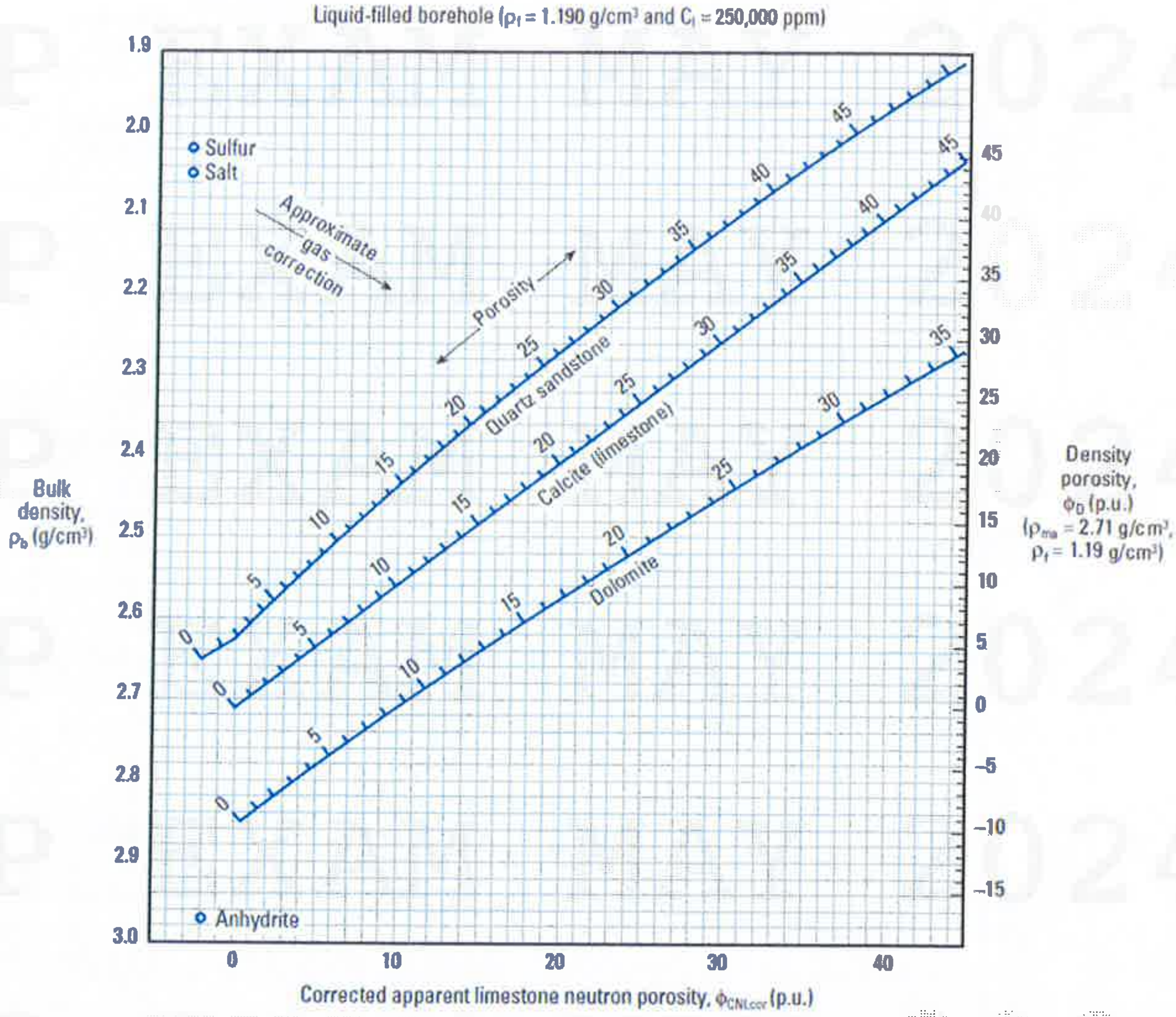
APPENDIX 3

Neutron Porosity and Bulk Density Measurement Combination, $\rho_f = 1.190$ g/cc



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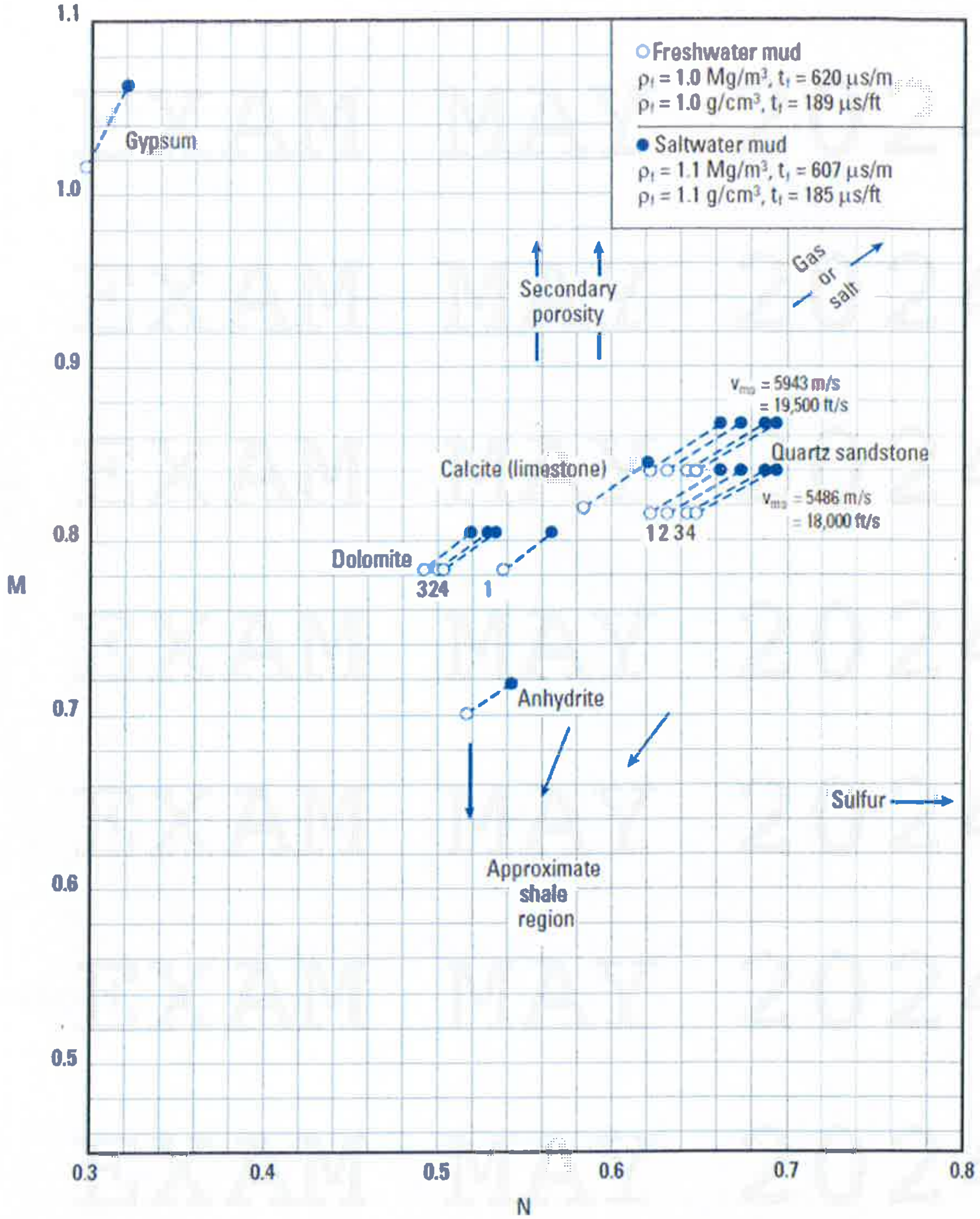
APPENDIX 4

MN plot



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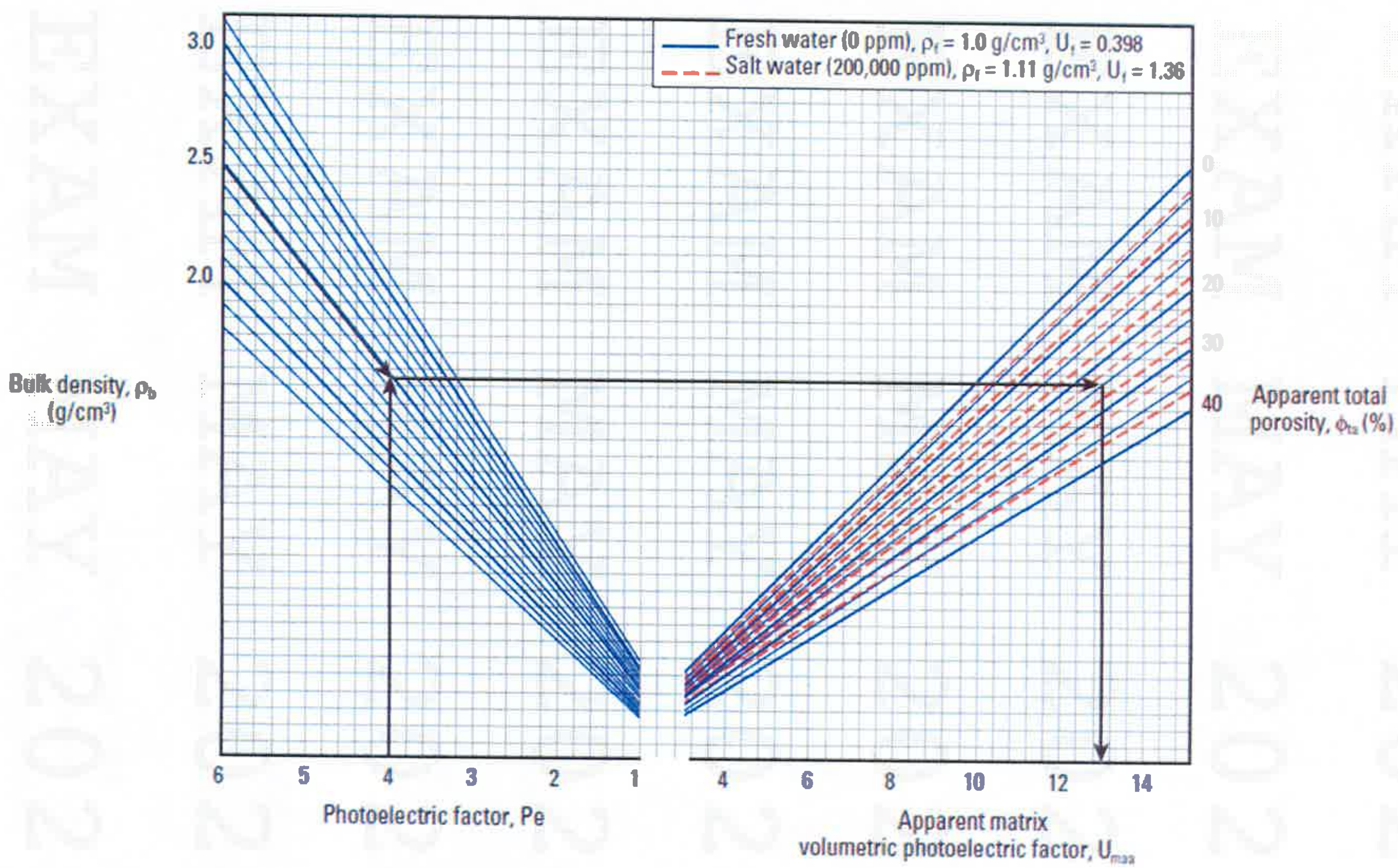
APPENDIX 6

Apparent Matrix Volumetric Photoelectric Factor – Open Hole



APPENDIX 7:

Useful Formulae

$$F = \frac{\tau^2}{\phi}$$

$$F = \frac{R_0}{R_w}$$

$$R = r\frac{A}{L}$$

$$\tau = \frac{L_e}{L}$$

$$n_e = \sum_{i=1}^{N} \kappa_i n_i$$

$$F = \frac{1}{\phi^m}$$

$$k \propto \frac{1}{\tau}$$

$$F = \frac{a}{\phi^m}$$

$$F = Ak^{-B}$$

$$\phi = Ck^{-D}$$

$$k = \frac{4 \times 10^8}{F^{3.65}}$$

$$k = \frac{7 \times 10^8}{F^{4.5}}$$

$$I_R = \frac{R_t}{R_0}$$

$$I_R = S_w^{-n}$$

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

$$S_{w,i+1} = \left(\left(\frac{aR_w}{\phi^m}\right)\left(\frac{1}{R_t} - \frac{V_{sh}}{R_{sh}}S_{w,i}\right)\right)^{\frac{1}{n}}$$

$$\frac{1}{R_t} = \frac{V_{sh}}{R_{sh}}S_w + \left(\frac{\phi^m}{a}\right)\frac{S_w{}^n}{R_w}$$

$$\mu = \frac{P_s}{\gamma}$$

$$S_w = \frac{-\frac{V_{sh}}{R_{sh}} \pm \sqrt{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \left(\frac{4}{FR_tR_w}\right)}}{\frac{2}{FR_w}}$$

$$K = \frac{\Delta P}{\Delta v / v_1}$$

$$V_P = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

$$V_P = \sqrt{\frac{K}{\rho}}$$

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_p - \Delta t_{ma}}$$

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_p - \Delta t_{ma}} \times \frac{1}{B_{cp}}$$

$$\frac{1}{\Delta t} = \frac{\phi}{\Delta t_p} + \frac{(1-\phi)^2}{\Delta t_{ma}}$$

$$\phi_{oil} = \frac{\phi_D + \phi_N}{2}$$

$$\phi_{gas} = \sqrt{\frac{\phi_D{}^2 + \phi_N{}^2}{2}}$$

For M-N Plot

$M = \frac{\Delta t_{fluid} - \Delta t}{\rho_b - \rho_{fluid}} \times 0.01$ and $N = \frac{\phi_{N,fluid} - \phi_N}{\rho_b - \rho_{fluid}}$

1. Tight formation, $\phi = 0$
2. Porosity, $0 < \phi < 0.12$
3. Porosity, $0.12 < \phi < 0.27$
4. Porosity, $0.27 < \phi < 0.40$

Formula	Lithology
$F = \frac{0.81}{\phi^2}$	Consolidated sandstone
$F = \frac{0.62}{\phi^{2.15}}$	Consolidated sandstone (Humble formula)
$F = \frac{1.65}{\phi^{1.33}}$	Shaly sands
$F = \frac{1}{\phi^{1.5}}$	Unconsolidated sands
$F = \frac{1.97}{\phi^{1.29}}$	Unconsolidated Miocene sands (US Gulf Coast)
$F = \frac{1.451}{\phi^{1.7}}$	Calcareous Sands
$F = \frac{1.01}{\phi^2}$	Limestones and Dolomites

- Linear Gamma Ray Index model, $V_{sh,linear} = I_{GR} = \frac{GR_{log} - GR_{clean}}{GR_{shale} - GR_{clean}}$
- Larionov Old Rock, $V_{sh,\,LarionovOldRock} = 0.33(2^{2I_{GR}} - 1)$
- Clavier Model, $V_{sh,\,Clavier} = 1.7 - \sqrt{3.38 - (I_{GR} + 0.7)^2}$
- Stieber, $V_{sh,\,Stieber} = \frac{I_{GR}}{3 - 2I_{GR}}$
- Larionov Tertiary Rocks Model, $V_{sh,\,LarionovTertiaryRocks} = 0.083(2^{3.7I_{GR}} - 1)$

Material	Δt (μs/ft.)	V (ft./s)	V (m/s)
Compact sandstone	55.6 – 51.3	18000 – 19500	5490 – 5950
Limestone	47.6 – 43.5	21000 – 23000	6400 – 7010
Dolomite	43.5 – 38.5	23000 – 26000	7010 – 7920
Anhydrite	50.0	20000	6096
Halite	66.7	15000	4572
Shale	170 – 60	5880 – 16660	1790 – 5805
Bituminous coal	140 – 100	7140 – 10000	2180 – 3050
Lignite	180 – 140	5560 – 7140	1690 – 2180
Casing	57.1	17500	5334
Water: 200,000 ppm, 15 psi	180.5	5540	1690
Water: 150,000 ppm, 15 psi	186.0	5380	1640
Water: 100,000 ppm, 15 psi	192.3	5200	1580
Oil	238	4200	1280
Methane, 15 psi	626	1600	490