EXERCISES PETROPHYSICS

AESB3341

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Section of Geophysics and Petrophysics

Introduction:

This course is an introduction to the basic elements of open-hole log interpretation. The emphasis is laid on log interpretation and not on tool measurement theory. During the first meetings relevant rock and fluid characteristics are introduced. Subsequent sessions show more complex interpretation techniques, by that using the most important logs, i.e. calipher-, tension- gamma ray, spontaneous potential, induction-, neutron-, density- and sonic - logs and cross-plots. The number of interpretation techniques is kept to a minimum. The most important relations are dealing with:

- Porosity, permeability and capillarity as a preparation for laboratory practicals.
- The resistivity of rock, pore fluid, mud and mud-filtrate (Archie) and by that porosity and Sw.
- Bulk density and porosity and by that shale volume determination.
- Lithology determination based on multiple log cross-plots and associated equations.
- Calculation of gross/net volumes of specified strata and/or formation fluids/gases.

Since this practical work is a part of the third year programme, the subjects are related to a wide field of interests. Petrophysics is an applied discipline, with connections and roots in many fields of exploration. Petrophysical interpretation is valuable for geophysics, water/oil exploration and reservoir engineering and ore/coal exploitation and by that they are sources for many petrophysical interpretation techniques. Examples of well log interpretations for various disciplines are:

Petroleum Engineering

From logs the following information:
- Reservoir thickness, gross/net.
- Reservoir properties, such as; porosities, permeability, rock strength, wettability, etc.
- Fluid content and properties; water, %, salinity, gas, oil.
- Environment of deposition.
- Source rock potential.

Geophysics

From logs the following information:
- Impedance as a product of density and sonic.
- Proper editing is needed, such as checks on caliper (washout sections useless to apply) environmental corrections such as; borehole size, mud type, invasion. In a gas bearing formation, the sonic shows erroneous velocities.
- With other logs the sonic-density can be reconstructed artificially.

Engineering Geology

Objectives of well logging surveys:
- Geological; thickness, depth to engineering rock bed, establishing weathering profiles, location of buried channels etc.
- Resource assessment; location of aquifers, determination water quality, exploration of sand, gravel and clay deposits.
- Engineering parameters; dynamic elastic moduli, rock quality.

Mining; exploration and exploitation.

Objectives of well logging surveys:
- Detection of ore bodies or other productive seams.
- Non recovered sections of cores can be correlated with logs.

Gold Exploration
- Gold associated with pyrite (high conductivities)

Coal logging

Lithology interpretations from:

- Sonic, density and neutron readings.
- 100% matrix responses of the minerals; coal consists of: carbon (Vcarb, Dcarb, dTcarb), ash (Vash, Dash, dTash) and moisture (porosity) (Vmois, Dfl, dTfl).

  $dT = dTfl.Vmois + dTash.Vash + dTcarb.Vcarb$

  $Dbu = Dfl .Vmois + Dash.Vash + Dcarb.Vcarb$

  $1 = Vmois + Vash + Vcarb$

  Three equations, three unknowns: Vash, Vcarb, Vmois

Many other purposes can be mentioned, especially regarding drinking water resources, environmental aspects such as groundwater contamination, the use of brine, nitrogen injection, sub-surface (nuclear) waste storage, underground coal gasification, etc.

USEFUL EQUIVALENTS

LENGTH

1 foot (ft)	30.48 cm
1 inch (in.)	2.540 cm
1 meter (m)	3.281 ft
"	39.37 in.

VOLUME

1 acre-foot	7,758 bbls
"	43,560 cu ft
1 barrel (bbl) of oil	42 U.S. gal
"	5.6154 cu ft
"	158.98 liters
1 cubic foot (cu ft)	7.481 U.S. gal
"	28.32 liters
1 U.S. gallon (gal)	231.00 cu in.
"	0.1337 cu ft
"	3.785 liters
1 imperial gallon (England, Canada, Australia, etc.)	1.2009 U.S. gal
"	4.5460 liters
1 liter (1000 cc)	0.03532 cu ft
"	0.2642 U.S. gal

MASS

1 grain	0.0001429 (or 1/7000 lb)
"	0.6480 g
1 pound (lb) avoirdupois	0.4536 kg
1 metric ton (1000 kg)	2205 lb

DENSITY, SPECIFIC GRAVITY, etc.

1 gram per cubic centimeter (g/cc)	62.43 lb/cu ft
"	8.345 lb per U.S. gal

1 U.S. gallon of liquid weighs (in pounds avoir.) 8.345 multiplied by density in g/cc

1 imperial gallon of water at 62°F weighs 10 lb

1 barrel of oil weighs (in pounds avoir.) 350 multiplied by density of oil in g/cc

Oil gravity in degrees API is computed as:

$$°API = \frac{141.5}{\text{Spec. Grav. 60/60F}} - 131.5$$

where "Spec. Grav. 60/60F" means specific gravity of oil at 60°F referred to water at 60°F

PRESSURE

1 atmosphere (atm)	14.70 psi
	1.0332 kg/sq cm
1 kilogram per square centimeter pressure (kg/sq cm)	14.22 psi
1 pound per square inch (psi)	0.07031 kg/sq cm
	0.06805 atm

Pressure Gradient

psi/ft. = 0.433 x g/cc
= $lb/ft^3/144$
= lb/gal/19.27

kg/sq cm/meter = 0.1 x g/cc
= psi/ft x 0.231

TEMPERATURE CONVERSIONS

°F = 1.8°C + 32
°C = 5/9(°F − 32)
°R(Rankine) = °F + 459.69
K(kelvins) = °C + 273.16

CONCENTRATION

1 grain/U.S. gallon	0.017118 g/liter
1 grain/U.S. gallon (in ppm)	17.118 divided by the density in g/cc
1 gram/liter	58.417 grains/gal
1 gram/liter (in ppm)	1000 divided by the density in g/cc

EXERCISES 1: POROSITY & PERMEABILITY

Question 1:

In Scheveningen a new giant sea aquarium is placed on a foot of Bentheimer sandstone. This porous sandstone is used to trap water during leakage. Unfortunately the aquarium burst and lost much water in de sandstone. The centre part is fully saturated with water and the question is: will the floor of the Scheveningen pier give away or not? or what is the porosity of the sandstone?
Dry core weight: 423 gram, density of the water: 1.05 $g.cm^{-3}$ and saturated weight: 461 gram. The sample dimensions are: 110 mm length and 38 mm diameter.

Question 2:

In Babylon American, Chinese, German, Dutch and African reservoir and hydrological engineers have to cooperate in the water and energy supply for the building of a big tower. Both absolute units and hybrid units are used to define permeability. In the end a conversion table is made to compare values. Fill the table with cgs-units (centimeter, gram, seconds), SI-units (m,kg,s), Darcy units, oilfield units and hydrological units.

			Absolute units			Hybrid units	
Parameter	Symbol	Dimension	SI	cgs	hydrology	Darcy	oilfiled
Length	I	L	m	cm			ft
Mass	m	M	kg	g			lb
Time	t	T					hr
Velocity	v	L/T					ft/sec
Rate	Q	L^3/T					stb/d (liquid) Mscf/d (gas)
Pressure	P	$(ML/T^2)/L^2$	N/m^2	$dyne/cm^2$		atm	psia
Density	ρ	M/L^3					lb/cu.ft
Viscosity	η	M/LT				cp	cp
Permeability	k	L^2				Darcy	mD ($10^{-15}m^2$)

Question 3:

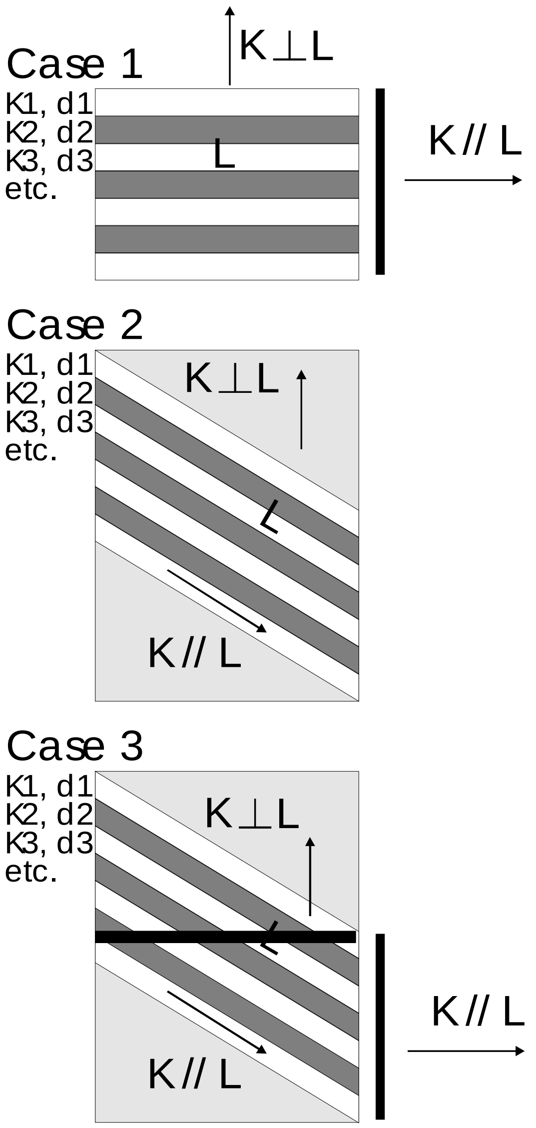
Good old Kozeny had problem with some ideas about grain surfaces. He did have a uniform sandstone with a permeability of 480 mD and a porosity of 17 %. He wanted to know:
- The average pore throat radius

- The surface specific areas of the pores S_{Vp} and grains S_{Vgr}.

He assumed that the flow channels were tubes. Use the equations 4.15 and 4.16 to solve this problem.

Question 4:

Compare the electrical resistivity of a body with the fluid resistivity when zones in a body do have different permeabilities or resistivities:



Question 5:

From a certain reservoir is known that it is an oil / water / solid water wet system;
The values from the laboratory are: r = 10 μm, ρ_{water}= 1.0, and ρ_{oil}= 0.7 g/cm^3 (10^3.kg/m^3)

The boss wants to know:

- the capillary pressure, P_c , and
- the capillary rise, h

Use table 4.6 to solve your problems.

Question 6:

From an oil reservoir the following parameters are known:

- IFT oil = 26 mN/m, with contact angle zero.
- Density difference of the brine/oil = 200 kg/m^3
- The laboratory measured a mercury/air capillary pressure curve with a maximum pressure of 100 bar.

use equation 4.37 and table 4.7 to solve your problems; the height of the free water level.

Question 7:

In Turkey a new small oil reservoir was detected in a slowly dipping and fractured layer. The part that reached the surface contained an aquifer filled with water from the mountains. Both the governement and the oil company wanted to know the reservoir permeabilities.
The government uses the conventional system (D) and the reservoir engineers use the units from the American oil industry (mD). Calculate both values with different units.
DATA:
Lab values:

- Cylindrical core: Length 100 mm, diameter 40 mm.
- Fluid viscosity: 2.5 cp
- Flow rate: 0.021 l/min

Pressure drop: 3.4 atm

EXERCISES 2: PRESSURES, STRESSES, SALINITIES AND ARCHIE

Part 1: Bad Bentheim: Resistivities, conductivities and pressures.

Bad Bentheim, accommodates a famous German "Kuhrort" for patients with serious skin diseases. Unfortunately the medical springs are depleting. Nevertheless, newly drilled exploration wells show highly porous sand bodies and fractured carbonate horizons in Jurassic sands and Bundsandstein formations, thus new prospects. The Delft Engineering Geological Group is asked to give an opinion on these findings, with respect to salinity, conductivity and reservoir quality of the drilled wells.

1. For the determination of the water salinities of the different sands, the following salinity results have to be converted to water resistivities at the formation depths e.g. formation temperatures. All resistivities are in ohm.m, FT is the formation temperature in °F or °C, 1 mol Na = 23 gram, 1 mol Cl = 35.5 gram). Use table Ex.1.
2. At the faculty all relevant information on borehole depth and bottom hole pressures have been stored in one computer. Unfortunately, during renovations this specific computer was stolen. Someone found in the literature the regional thermal gradients, with an average estimated gradient of G_t=30.5°C/km. The average surface temperature is 14°C. Calculate the bottom hole depths and put them in table E1.
3. Now it is also good to know the bottom hole pressures for engineering purposes. Here the salinity and depth are needed.
4. In order to get acquainted with the stability of the porous sandstones, one likes to know the effective stress σ_p on the grain framework. An average bulk density (ρ_r) of 2.31 g/cm^3 is normal in these areas.

Table Ex.1

Well nr	Bottom hole depth in km	Formation water salinity	$\rho_{f\ NaCl}$ in g/cm^3	P_f in bar	P_0 in bar	ft	Rw at ft in ohm. m	σ_p in MPa
1		200,000 mg/l NaCl				212 °F		
2		100,000 ppm NaCl				122 °F		
3		50,000 ppm NaCl				130 °F		
4		50,000 mg/l Cl				122 °F		
5		100 g/l NaCl				100 °C		

5. A sixth well was analyzed on the ion-content of the formation water at a surface temperature of 75°F. Further information was vanished. Further information was vanished. The concentrations are: 8000 ppm Na^+, 10000 ppm Cl^-, 5000 ppm Mg^{2+}, 3000 ppm Ca^{2+}, 7000 ppm CO_3^{2-}
   - Determine the solid concentration and the equivalent NaCl concentration.
   - Determine the resistivity at reference temperature and resistivity of the brine at 130°F.

Part 2: Bad-Bentheim & archie

After the first appraisal some coring work was done in order to characterize the reservoir capacities of the brine. The prospective clean sand and carbonate layers are studied. Cores have been obtained and tested in laboratories on their porosities, water salinities etc. These porosities, combined with "Schlumberger-standard" cementation exponents, give a view on the Formation factor (F), in-situ water + rock salinity (Ro) and water saturation (Sw in %).

Complete the tables with the information from the reader.

Table 1.

Formation	φ	m in-situ	F
Very hard sandstone	10		
Hard sandstone	15		
Limestone, I-BCD, inter-conn.	18	2.2	
Friable sandstone	22		
Limestone, II VF A	20	2	
Unconsolidated sandstone	30		

Table 2.

Formation	φ	m in-situ	F	Rw at FT	Ro at FT
Very hard sandstone	10			0.04	
Friable sandstone	20			0.03	
Dolomite, III-F, A	10	2		0.08	
Unconsolidated friable sand	25			0.017	
Unconsolidated friable sand	25			0.37	
Unconsolidated sand	29			70	

Many parts of the Bentheimer sandstone formation are also recognized in more northerly parts of the area. In these sands the formation sometimes is acting as a reservoir. In the cores of our target area some zones also contained some minor oil-bearing zones. They have to be isolated to avoid pollution of the brine. Hence water saturations have to be calculated.

Table 3:

Formation use n=2	**m**	**φ**	**Rt at FT**	**Rw at FT**	**Ro**	**Rt/Ro**	**Sw%**
Very hard sandstone	2.2	10	80	0.08			
Uncons.friable sand	1.7	12	50	0.05			
Hard sandstone	2	18	40	0.04			
Friable sandstone	1.8	22	12.4	0.04			
Very hard sandstone	2.2	8	12.4	0.08			

Table 4:

Formation use n=2.	**m**	**φ**	**NaCl g/l**	**FT (F)**	**Rw**	**Ro**	**Rt**	**Sw (%)**
Uncons.friable SST	1.7		5	170			3	100
Hard sandstone	2.0	25		120	0.03		3	
Very hard sandstone	2.2	20	10	130			10	
Very hard sandstone	2.2	20		200	0.08			68
Limestone (m = 2.0)	2.0		20	175			10	100
Hard sandstone	2.0			200	0.08		30	16

EXERCISES 3: THE PRACTICAL USE OF ARCHIE, DATA-CONVERSION AND ACCURACIES

Introduction:
This example shows logging results used for the determination of hydro-carbon presence and quantities in a reservoir. This method is also used for the definition of:
- coal seam-thickness and the amount of sterile zones in and between coal layers.
- clay type and its purity (for ceramic industrial purposes).
- ore exploration and exploitation (interpretation of the shape of an ore body).
- etc.

In the near future, many Russian oil provinces promise to be the main supplier of hydro-carbons for Western-Europe. Many of these giant oil fields are producing, but are very poorly developed. As a try out, a Dutch/American consortium consisting of oil companies, banks and insurance companies, intend to put a high risk investments in the UTOPIA-field. Many well data have been evaluated. These pre-perestroika figures are produced in a Marxist-Leninist climate and difficult to interpret for "profit-based" exploitation purposes. For this reason a new appraisal well is drilled by DEDRI (Delft Drilling BV i.o.) and evaluated by DUPE (Dutch- Petrophysics V.O.F.).

Relevant data, known after drilling, logging and core-evaluation of this well **OLGA - XIII** are:

Well OLGA - XIII

Core and plug results:
- The section 7050 - 7120 ft. was continuously cored.
- The reservoir is a friable sandstone, non-calcareous and shale free.
- The results of the routine core analysis are shown on the log.
- Sidewall samples were taken in the zone 7000 - 7020 ft. This is a hard clean sandstone. No oil or gas shows were observed in the samples nor in the mud while drilling through this section.
- Maximum depth logged; 7140 ft.

Drilling information:
- Bottom hole temperature; 174˚F.
- Bit size; 8".
- Mud type; Caustic Quelracho, mud density-10.2 lbs/gal.

Additional information:
- Saturation exponent; n = 1.6
- 1 acreft = 1233 m^3
- No borehole or bed thickness corrections are required

The next two pages show:
- The questions of this exercise.
- Some logs and core/plug results.

Define the following in-situ resistivities:

Resistivity mud	0 .7 ohm m at 77˚F	....	ohm m at 174˚F
Filtrate resistivity	0.5 ohm m at 77˚F,	....	ohm m at 174˚F
Rw in the bottom sand	0.14 ohm m at 77˚F	....	ohm m at 174˚F
Rw in top sand	0.058 ohm at 77˚F	....	ohm m at 174˚F

Questions

1) What "m" would you consider for the bottom sand?

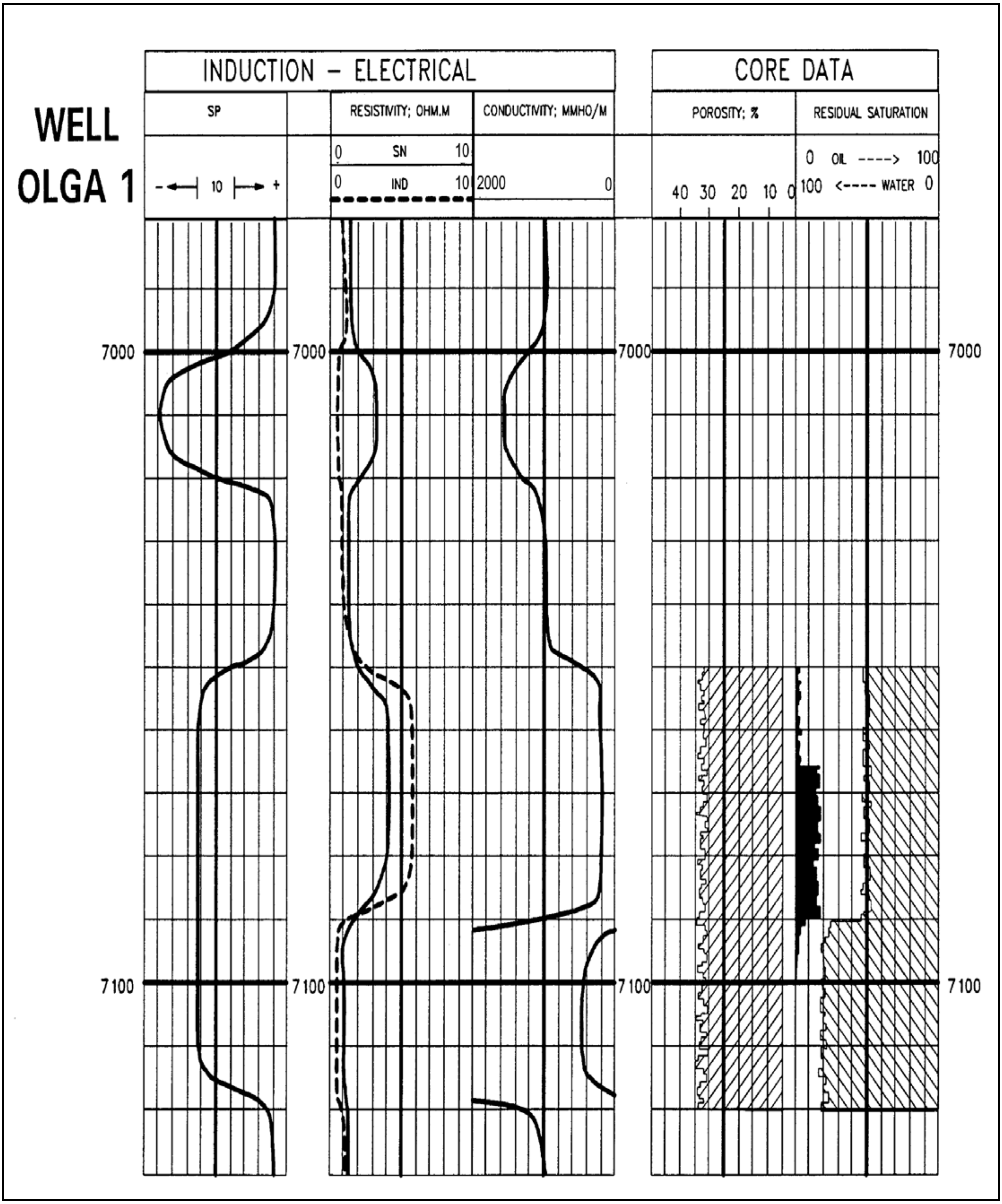
2) What "m" would you consider for the top sand?

3) Calculate the amount of Oil In Place in barrels per acre in the lower sandstone, taking into account the information provided by the core data. (Determine Ro bottom sand in two ways).

4) What is the water saturation Sw at 7010 ft.?

5) Estimate the porosity of the upper sandstone using;
   a) the resistivity indicated by the induction log?
   b) the resistivity indicated by the short normal?

6) Are the values found in 5a) and 5b) minimum or maximum values?


WELL
OLGA 1
INDUCTION – ELECTRICAL
SP
- 10 +
RESISTIVITY; OHM.M
0 SN 10
0 IND 10
CONDUCTIVITY; MMHO/M
2000 0
CORE DATA
POROSITY; %
40 30 20 10 0
RESIDUAL SATURATION
0 OIL ----> 100
100 <---- WATER 0
7000
7100

EXERCISES 4: EVALUATION OF A SANDSTONE RESERVOIR USING THE DENSITY LOG AND VARIOUS RESISTIVITY LOGS

During this exercise cooperation improves the results. Therefore, groups of two students are working together.

Objectives:

- Getting acquainted with the use of rock densities, resistivities and conductivities.
- Determination of a Carboniferous sequence of sandstone and shale layers. In this case gas is an important objective. A comparable evaluation can be made for Carboniferous coal seams or fresh water resources.

Well: Saturnus

Logs available: one sheet for two students.

- Composite log including Gamma ray, Laterolog 7, Formation Density, Induction, Microlaterolog and Sonic.

NOTE: Look on Blackboard in the list with abbreviations what will be the codes for these tools.

Reservoir characteristics

- The formation consists of a Carboniferous sandstone with shale breaks. This type of sandstone may have anomalously high and variable matrix densities. Core data are therefore essential for proper formation evaluation. The upper part of the reservoir is gas bearing, the lower water bearing. Approximate straight line relationships between bulk density and porosity for the gas and the water bearing sections were derived from the core data.
  These can be represented by the following values:
  - gas bearing section : ρ_{ma} = 2.78 g/cc ; ρ_b = 2.11 g/cc for φ = 30%
  - water bearing section : ρ_{ma} = 2.78 g/cc ; ρ_b = 2.19 g/cc for φ = 30%
  - Formation temperature : 120˚F

Mud data

- Density (ρ) : 1.45 g/cc
- Waterloss : 3.2 ml
- Rm : 0.07 ohm.m at 21˚C
- Rmf : 0.05 ohm.m at 16˚C

THE LOGS ARE AVAILABLE ON AN A3 SHEET ON BLACKBOARD UNDER THE NAME “SATURNUS”. PLEASE COPY THE ENTIRE LOG ON A3 OR LARGER!!!!

Questions:

1) Porosity calibration

Using the core data given above, construct the lines relating bulk density and porosity in the gas bearing and in the water bearing zones (Fig. 1).

2) Water bearing section

In table 1, the Induction log readings of several water bearing intervals are listed.

Note: The Induction log is usually less suitable than the Laterolog in salt saturated mud due to the strong borehole effect when Rt >> Rm. Here, the tool was set at zero in the borehole opposite a non-conductive formation. Thus the borehole effect is cancelled out, at least for a particular borehole size. Small variations in the borehole size may be neglected, especially since the contrast between Rt and Rm is small. Furthermore the resistivities opposite the water bearing layers are too low to be read accurately from the Laterolog. The conductivity curve from the Induction log was used instead to determine the resistivities.

- Read the formation bulk densities for the intervals selected in table 1.
  Translate these into porosity using figure 1.

- Plot resistivity versus bulk density ρ_b in Fig. 2, assuming m = 2.
  Add a porosity scale to the ρ_b - axis.
  Determine the value of R_w .

- Read the Microlaterolog resistivities.
  Compare these values with those given by the Induction log.
  Which conclusion can you draw?

- Above we assumed m = 2. Considering now the invaded zone and the corresponding resistivities (R_{MLL} and R_{mf}); calculate for each interval the value of m.
  What average m do you obtain?

- Would a value of m different from 2 appreciably affect the final result of the evaluation?

3) Gas bearing section

Now resistivities can be read accurately from the Laterolog on its logarithmic scale.

- Read the resistivity of beds 1 to 12 (Table 2).

- Convert bulk densities into porosity values.

- Plot resistivity versus porosity on the m = 2 grid paper (Figure 3).

- Construct the iso-saturation lines (S_w = 90%, 80%, 70%, etc.).

- Determine graphically the water saturation of each interval and complete Table 2.

WELL: SATURNUS

Table 1: Water bearing section.

Bed	**Interval (m)**	ρ_b	**C**	**R**	ρ_{FDC}	R_{MLL}	**m**
N˚	**Depth GR - FDC**		**mmho/m**	**ohm.m**	**%**	**ohm.m**	
13	2433.2 - 2434.8		2500				
14	2440.3 - 2441.8		4000				
15	2449.3 - 2450.8		3600				
16	2451.2 - 2452.5		2300				
17	2448.4 - 2460.0		3200				
18	2465.8 - 2467.2		2000				
19	2473.0 - 2474.0		4700				
20	2474.0 - 2476.3		2600				
21	2477.4 - 2478.0		4700				
22	2479.0 - 2480.0		3100				

Table 2: Gas bearing section.

Bed	**Interval (m)**	ρ_b	R_{LL}	φ_{FDC}	S_w
N˚			**ohm.m**	**%**	
1	2366.0-2367.0	2.47			
2	2371.6-2372.2	2.43			
3	2383.0-2384.1	2.45			
4	2385.4-2386.9	2.42			
5	2392.5-2394.2	2.51			
6	2398.6-2399.8	2.33			
7	2403.0-2405.5	2.38			
8	2413.0-2415.5	2.40			
9	2417.0-2418.5	2.42			
10	2420.0-2421.5	2.40			
11	2425.8-2427.5	2.38			
12	2429.1-2430.0	2.39			

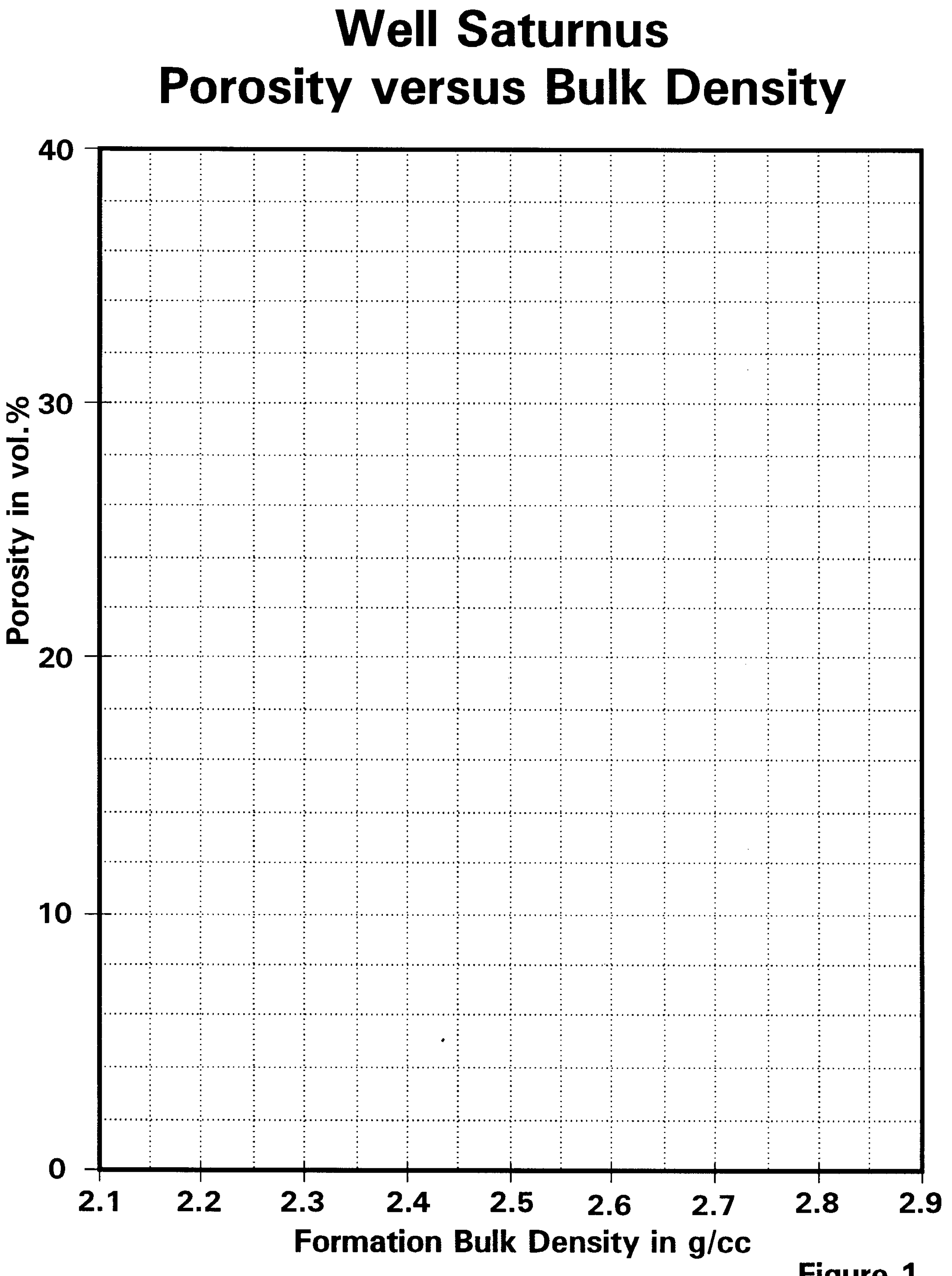

Well Saturnus
Porosity versus Bulk Density
40
30
20
10
0
Porosity in vol.%
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
Formation Bulk Density in g/cc

Figure 1

POROSITY VS RESISTIVITY

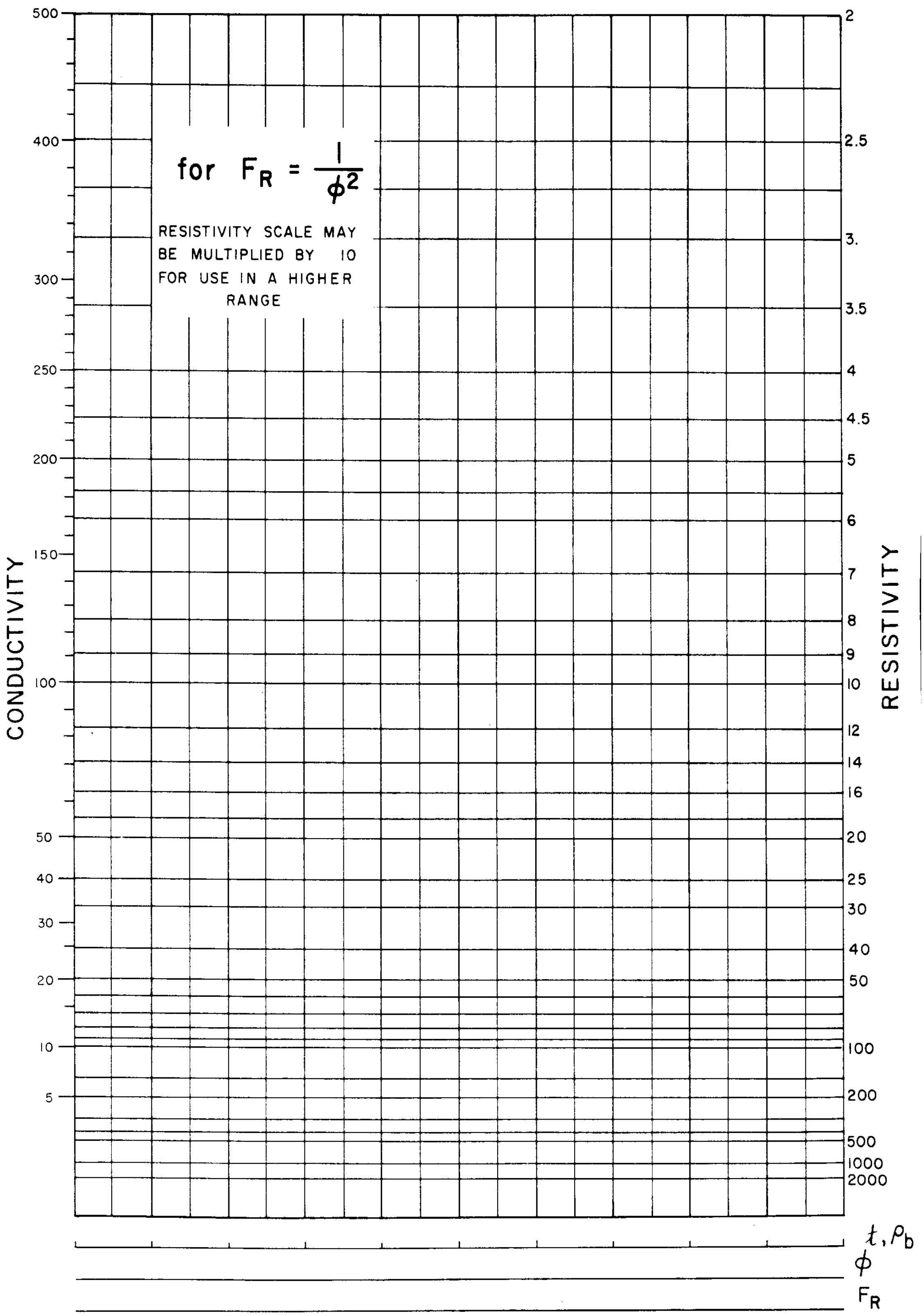


figure 2

POROSITY VS RESISTIVITY

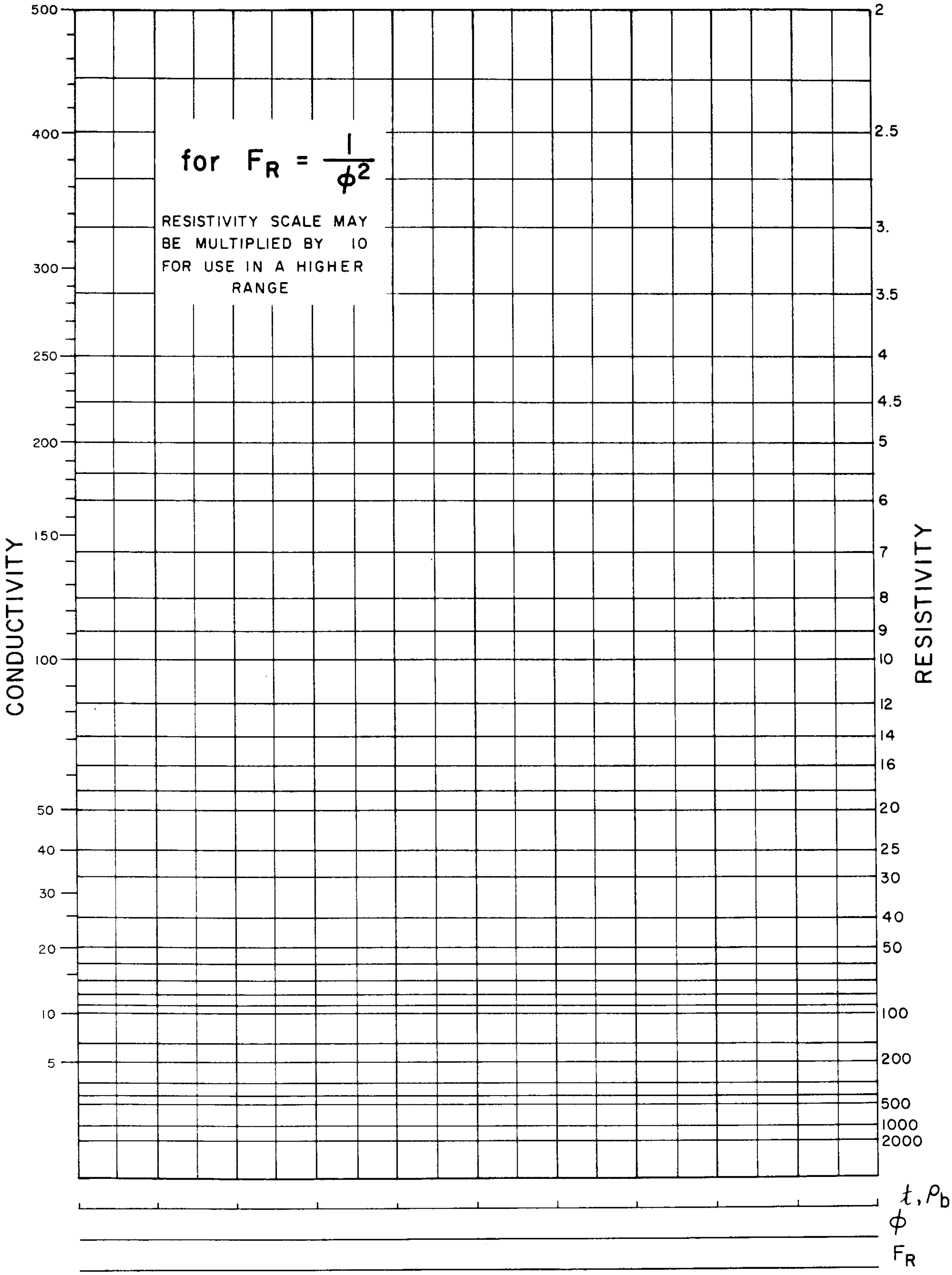


figure 3

EXERCISES 5: EVALUATION OF A SANDSTONE RESERVOIR; HOW TO SQUARE LOG READINGS AND THE DETERMINATION OF THE NET THICKNESS

Objectives:

- Getting acquainted with the relations between FDC-CNL logs, porosity and shaliness of sandstone and shales..
- In this case porosity determination is an important objective. A comparable evaluation can be made for:
  - water-influx tests from roof rock of coal seams and ore bodies.
  - determination of the vertical lithology in fresh water reservoirs.

Well SIMPLE-6

Reservoir characteristics:

- The formation is an unconsolidated sandstone.
- Matrix densities measured on the core: approximately 2.65 gr/cc.
- Formation temperature: 58˚C.
- Qv-values measured on the core are approx. 0.04 meq/ml PV.
- Formation water salinity = 85000 ppm NaCl.
- m = 1.6

Mud characteristics

- Rmf = 0.055 Ohm.m at 58˚C , thus 73000 ppm
- <u>The Rlld does not have to be corrected for borehole and invasion effects.</u>

Questions

- Finish table 1 down to 1265 m **<u>(square Density and Neutron only).</u>**
- Plot the layers in a Density-Neutron cross plot.
- Determine fluid in the pores (Gas/Oil/Water).
- Calculate for the gas cap:
  - Net sand thickness,
  - Mean porosity,
  - Mean Sh,
  - Sh-column.
- Determine for each layer in interval 1250 -1265, using FDC-CNL plot:
  - Shaliness,
  - Total and effective porosity (wet shale density = 2.55 gr/cc, shale Neutron por = 36 **<u>p.u</u>**., dry shale density = 2.65 gr/cc.)

Table 1: Squared and multiplexed log-values

Top	Depth	Density	Neutron	Rlld	φ total	Sw	Fluid
Layer	(m)	(g/cc)	(p.u.)	(ohm.m)	(%)		type
1*	1240.2		27	6			
2	1240.9		24	6			
3	1241.4		24	6			
4	1242		7	90			
5	1242.5		7	140			
6	1243.3		6	55			
7	1244		8	200			
8	1244.4		6	60			
9	1245.1		29	60			
10	1245.9 1247.5		29	270			

*Layer 1 refers to the interval from 1240.2 - 1240.9 m. The depth in this column indicates the top of the layer.

Table 2: Gas net count results

Interval	thickness "h"	φ	h * φ	Shc	h * φ * Shc
(m)	(m)		(m)		(m)

Mean porosity : ....
Porosity column : ....
Mean Shc : ....
h.c. column : ....

Table 3: FDC-CNL porosity and Vsh

Layer	Depth	Density	Neutron	Vsh	φ total	φ eff
	(m)	(g/cc)	(p.u.)			
11	1247.5					
12						
13						
14						
15						
16						
17						
18						
19						
20						

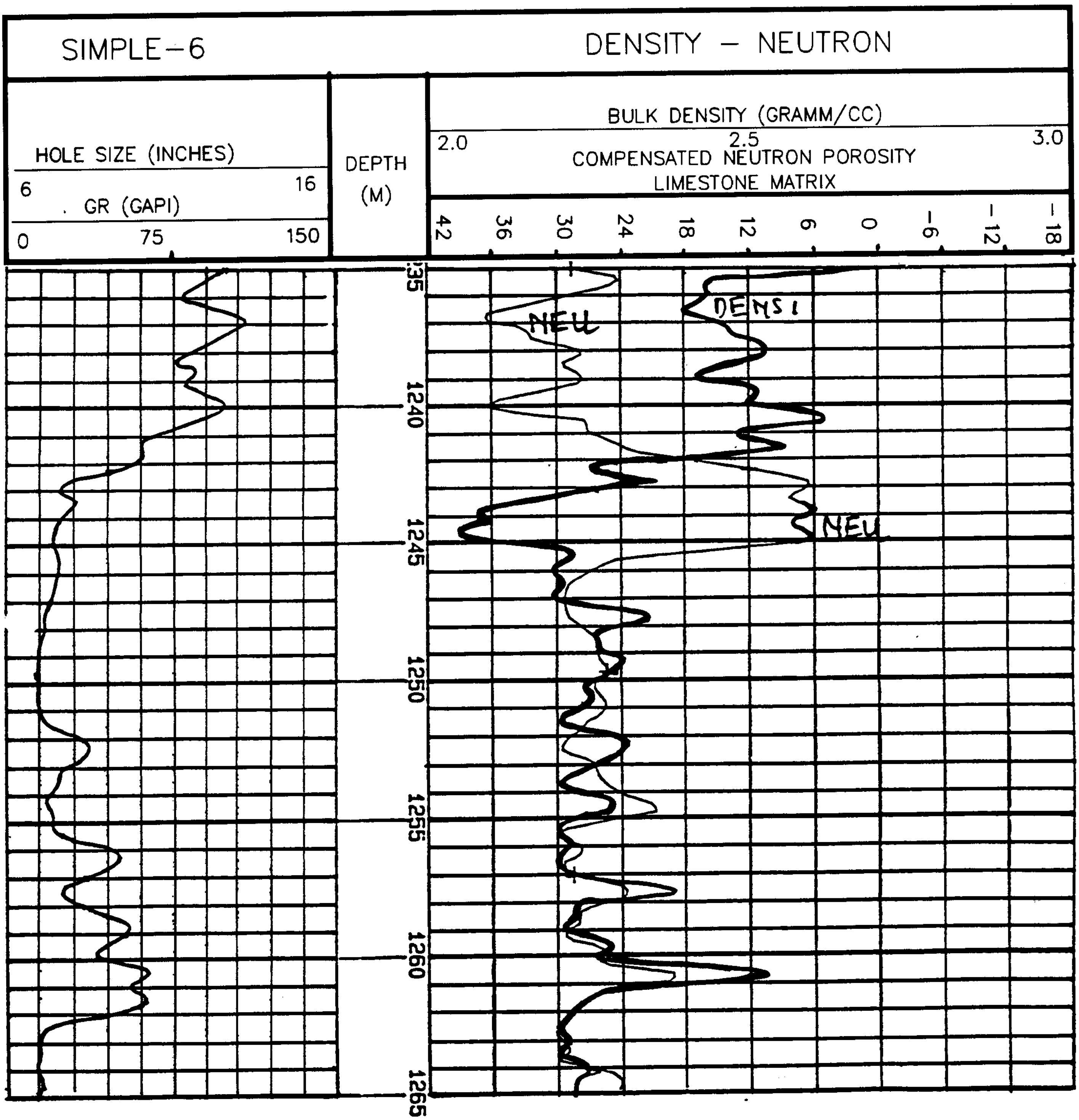


Figure 1; FDC, CNL, GR

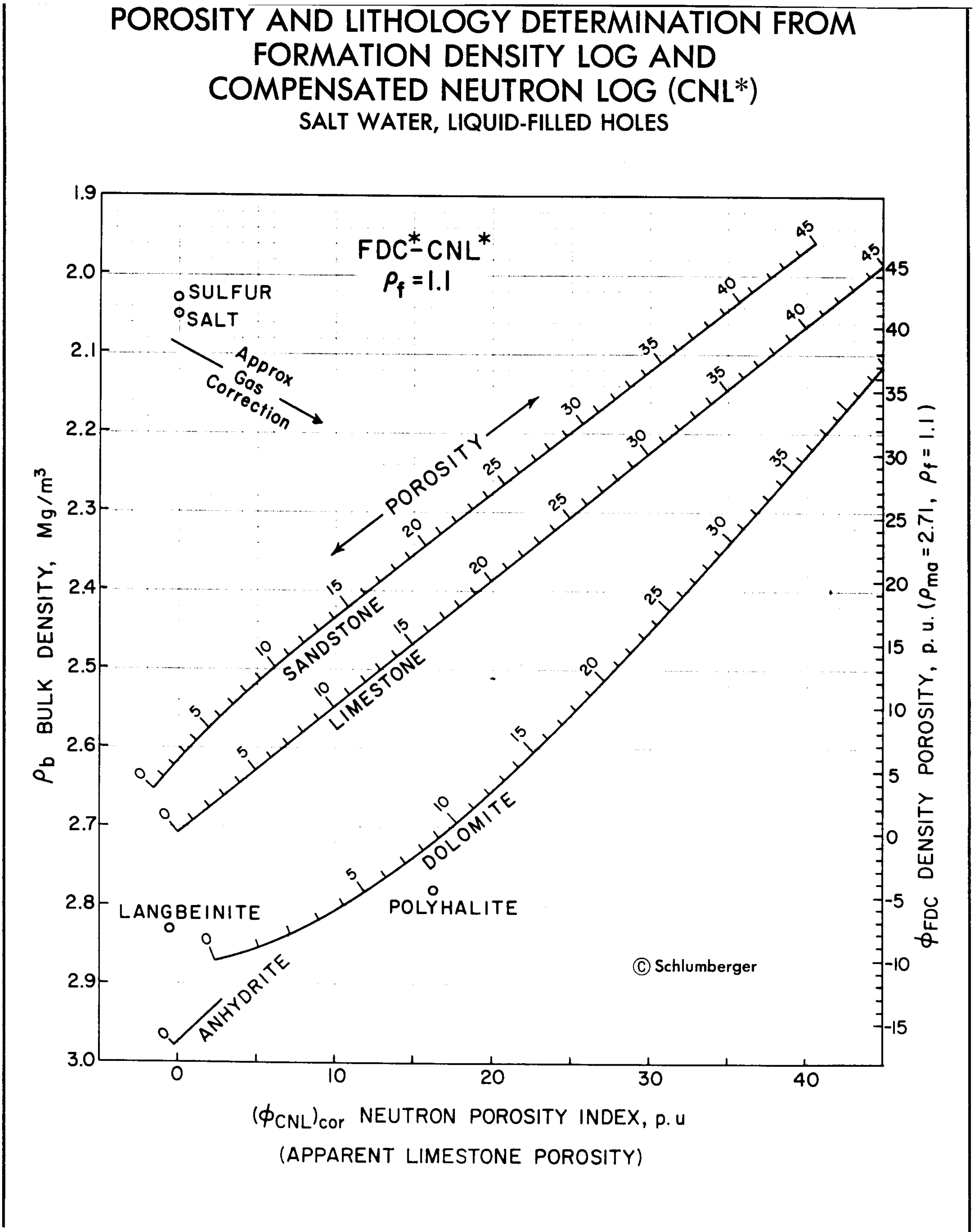


Figure 2: FDC-CNL plot, limestone compensated

EXERCISES 6: EVALUATION OF A SANDSTONE RESERVOIR; HOW TO SQUARE LOG READINGS AND THE DETERMINATION OF LITHOLOGY WITH VARIOUS LOGS

Objectives:

- Getting acquainted with the relations between FDC-CNL, CNL-SONIC, FDC-SONIC, MID- and M-N plot and their relations to lithology definition.
- In this exercise correlating and squaring of logs is an important purpose for the determination of porosity . A comparable evaluation can be made for:
  - porosity of surrounding rocks around coal seams and ore bodies.
  - determination of the vertical lithology in fresh water reservoirs.

Well TUFFY -3

The well has encountered two possible reservoir sections, the Sollingen sandstone and the Detfurth. These formations are found in wide areas of Northern-Germany, The Netherlands and the North Sea as:

- Marker seams.
- Potential reservoir sands for oil, gas and water.

Reservoir characteristics:

- BHT = 83˚C (at reservoir depth)
- Petrophysical parameters: m = 1.8, n = 2.0.
- The formation water has been assumed to be fully salt saturated (250000 ppm): Rw = 0.016 ohm.m at FT.

Production test results:

- Detfurth : 158106 m^3/day gas at 50 bar draw down
- Sollingen: not tested

Mud characteristics

- Mud type: salt water mud
- Rm = 0.076 Ohm.m at 22˚C = 105000 ppm = 0.030 Ohm.m at BHT
- Rmf = 0.046 Ohm.m at 22˚C = 210000 ppm
- Rmc = 0.26 Ohmm at 22˚C

General information

Bit size = 12 1/4 inch

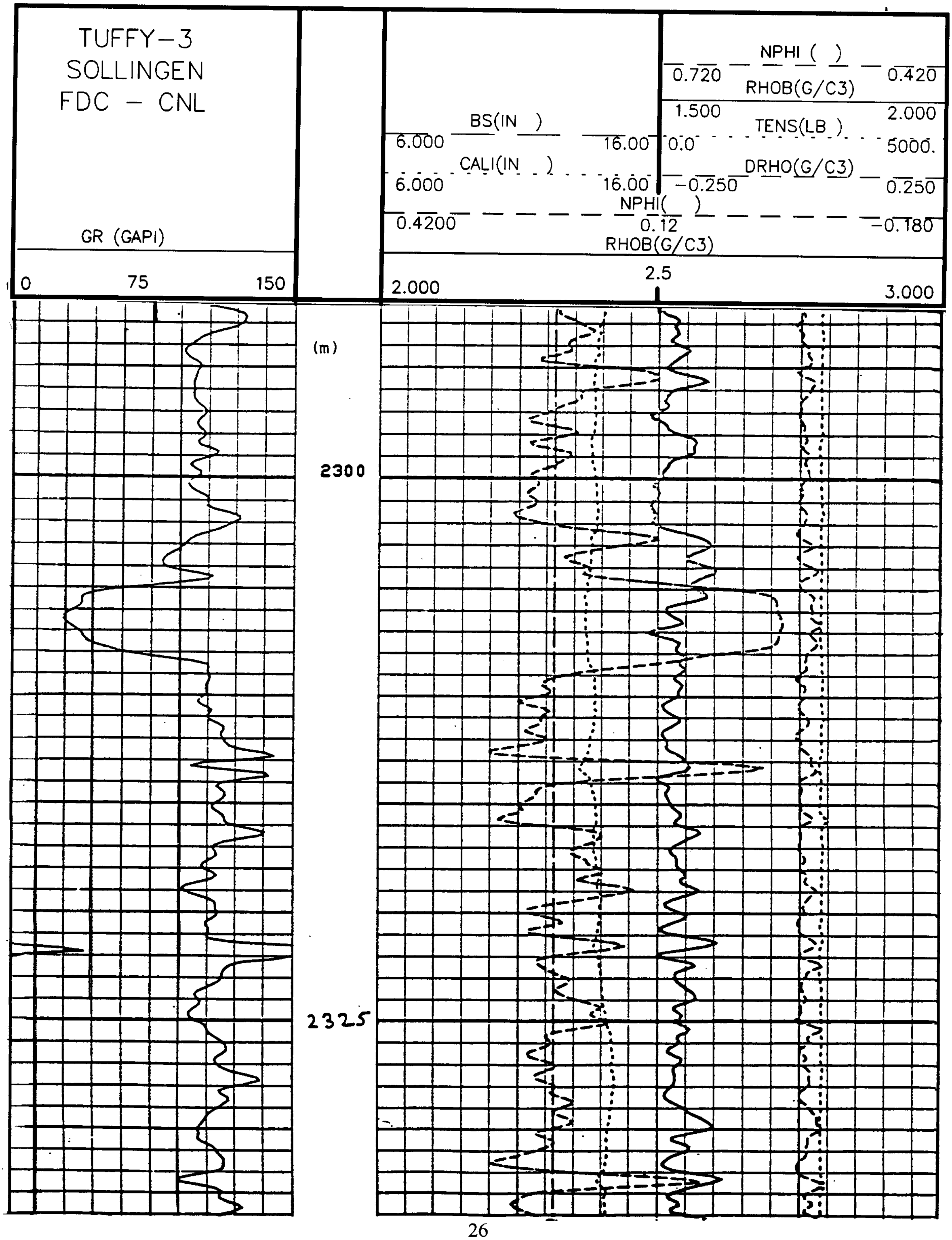
QUESTIONS

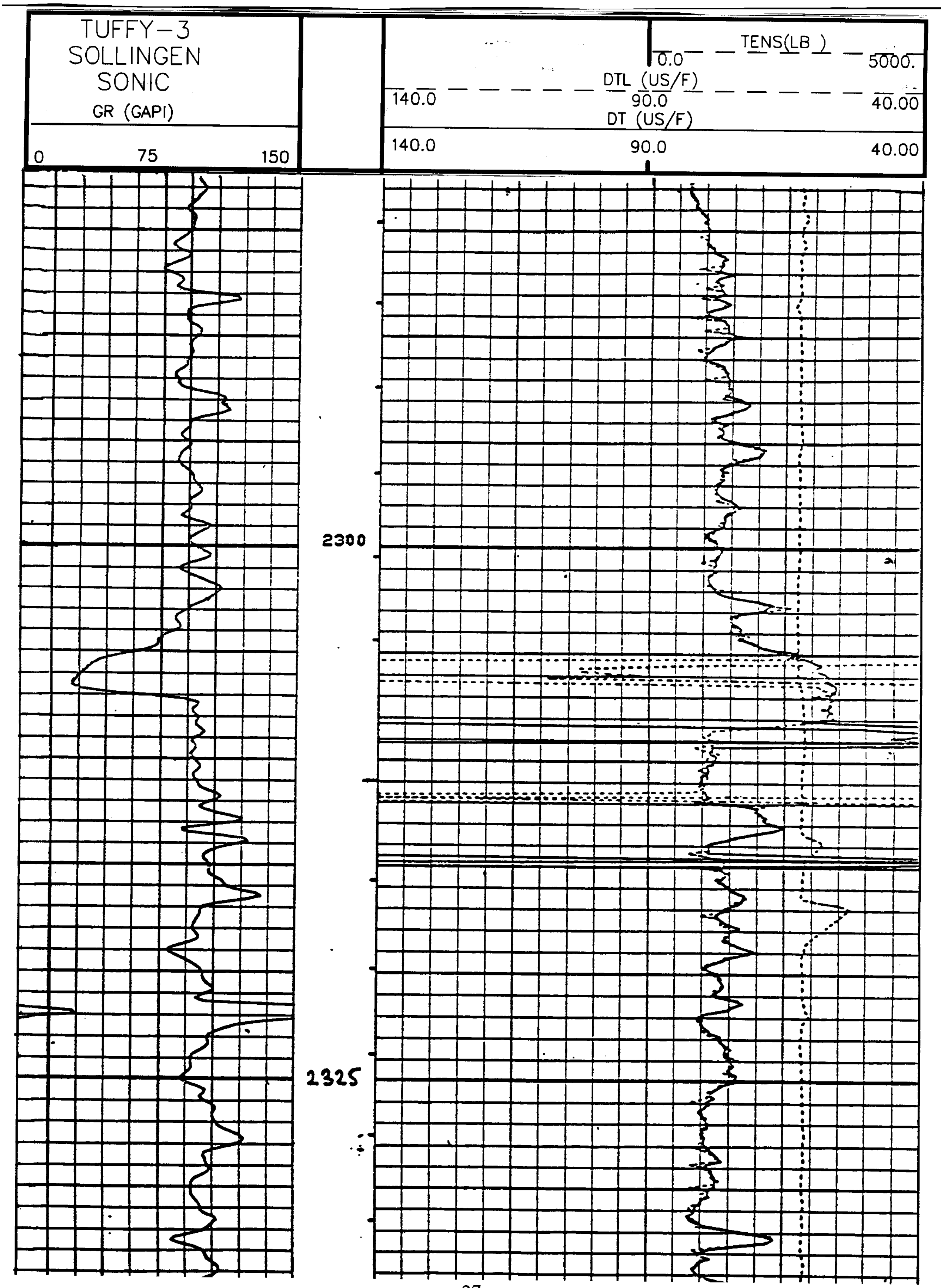
Sollingen Sandstone

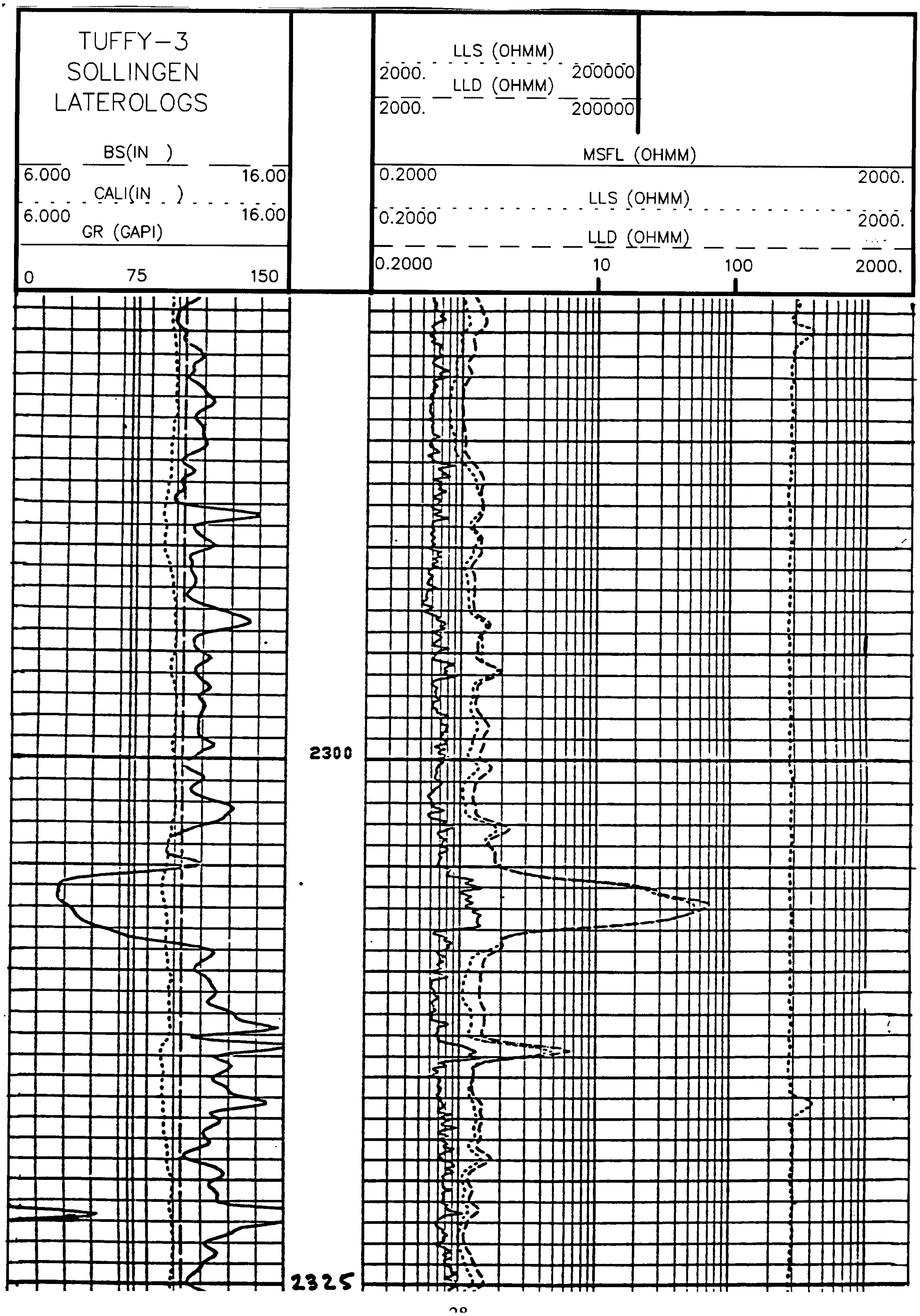
- Correlate and square the logs of the Sollingen Sandstone section.
- Correct the resistivities for borehole and invasion effect.
- Determine the lithology, using FDC-CNL, SONIC-CNL, MID- and M-N plot.
- Explain the position of the plotted points.
- Calculate Sw using Archie.
- What would be the effect when the pores are filled with salt water and how can it be observed?

Table Tuffy-3

Layer	Depth	Density	Neutron	Rlld	Sonic	Rlld	φ	Shc
No.	(m)	(g/cc)	(p.u.)	(ohm.m)	(μs/ft)	(ohm.m)		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								


TUFFY-3
SOLLINGEN
FDC - CNL
GR (GAPI)
0
75
150
BS(IN)
6.000
16.00
CALI(IN)
6.000
16.00
NPHI( )
0.4200
0.12
RHOB(G/C3)
2.000
2.5
3.000
NPHI ( )
0.720
0.420
RHOB(G/C3)
1.500
2.000
TENS(LB)
0.0
5000.
DRHO(G/C3)
-0.250
0.250
-0.180
(m)
2300
2325
26

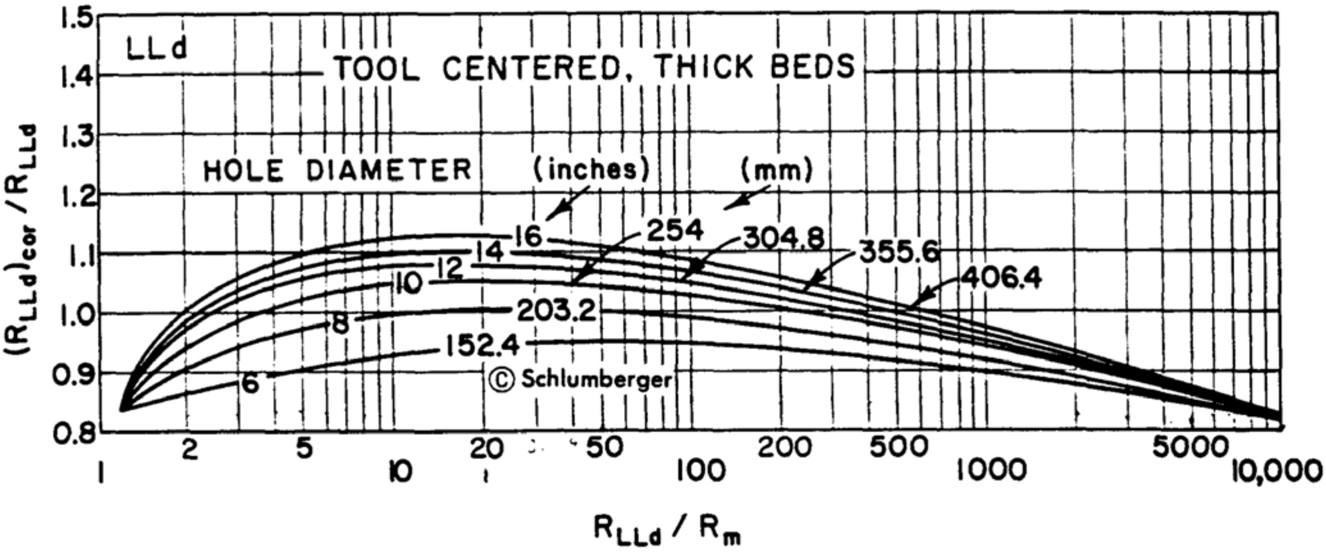

TUFFY-3
SOLLINGEN
SONIC
GR (GAPI)
0
75
150
TENS(LB)
0.0
5000.
DTL (US/F)
140.0
90.0
40.00
DT (US/F)
140.0
90.0
40.00
2300
2325
27

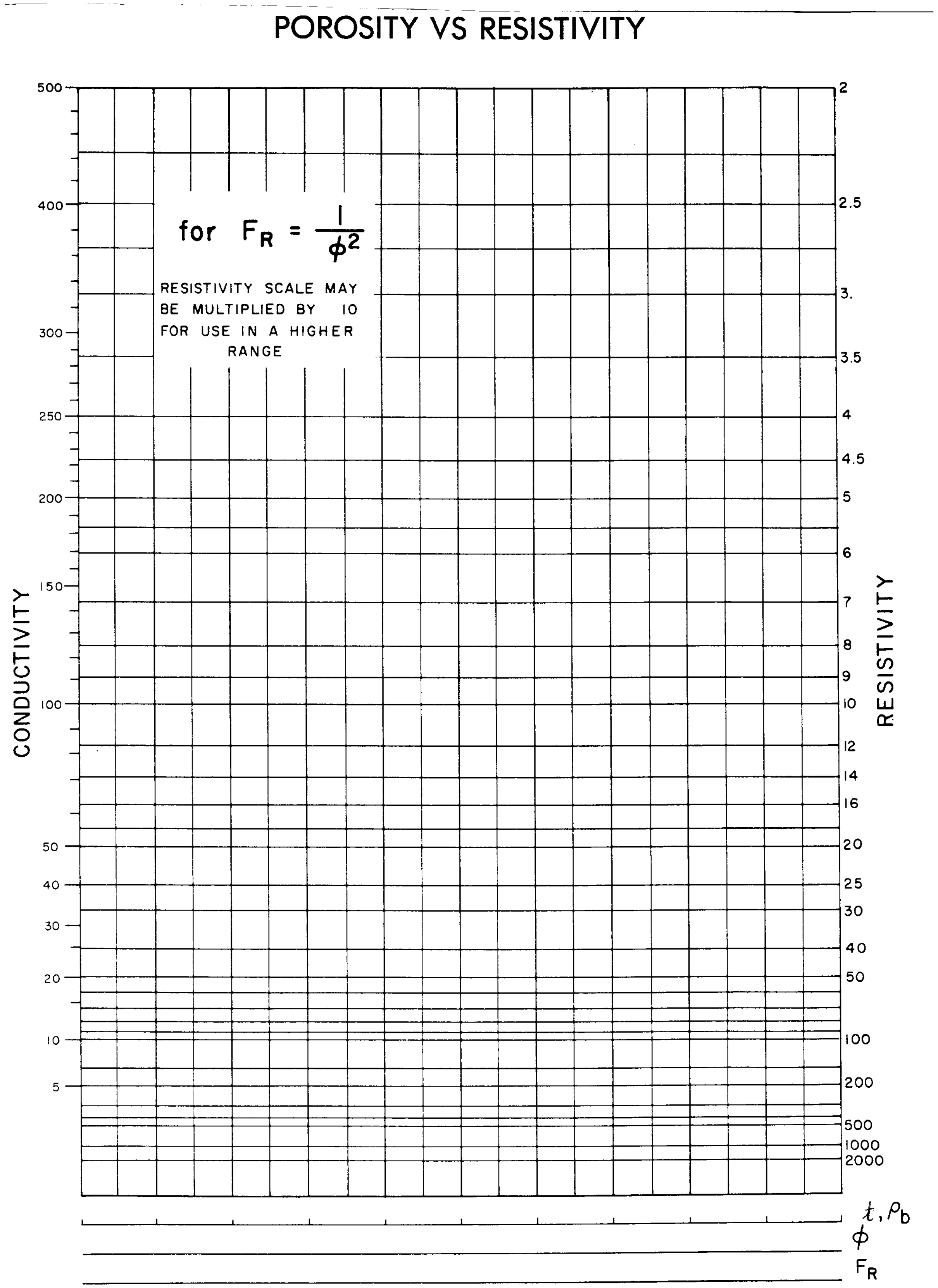

TUFFY-3
SOLLINGEN
LATEROLOGS
BS(IN)
6.000 16.00
CALI(IN)
6.000 16.00
GR (GAPI)
0 75 150
LLS (OHMM)
2000. 200000
LLD (OHMM)
2000. 200000
MSFL (OHMM)
0.2000 2000.
LLS (OHMM)
0.2000 2000.
LLD (OHMM)
0.2000 10 100 2000.
2300
2325

DUAL LATEROLOG* CORRECTION CHARTS

SONDE CENTERED

DEEP LATEROLOG* BOREHOLE CORRECTION

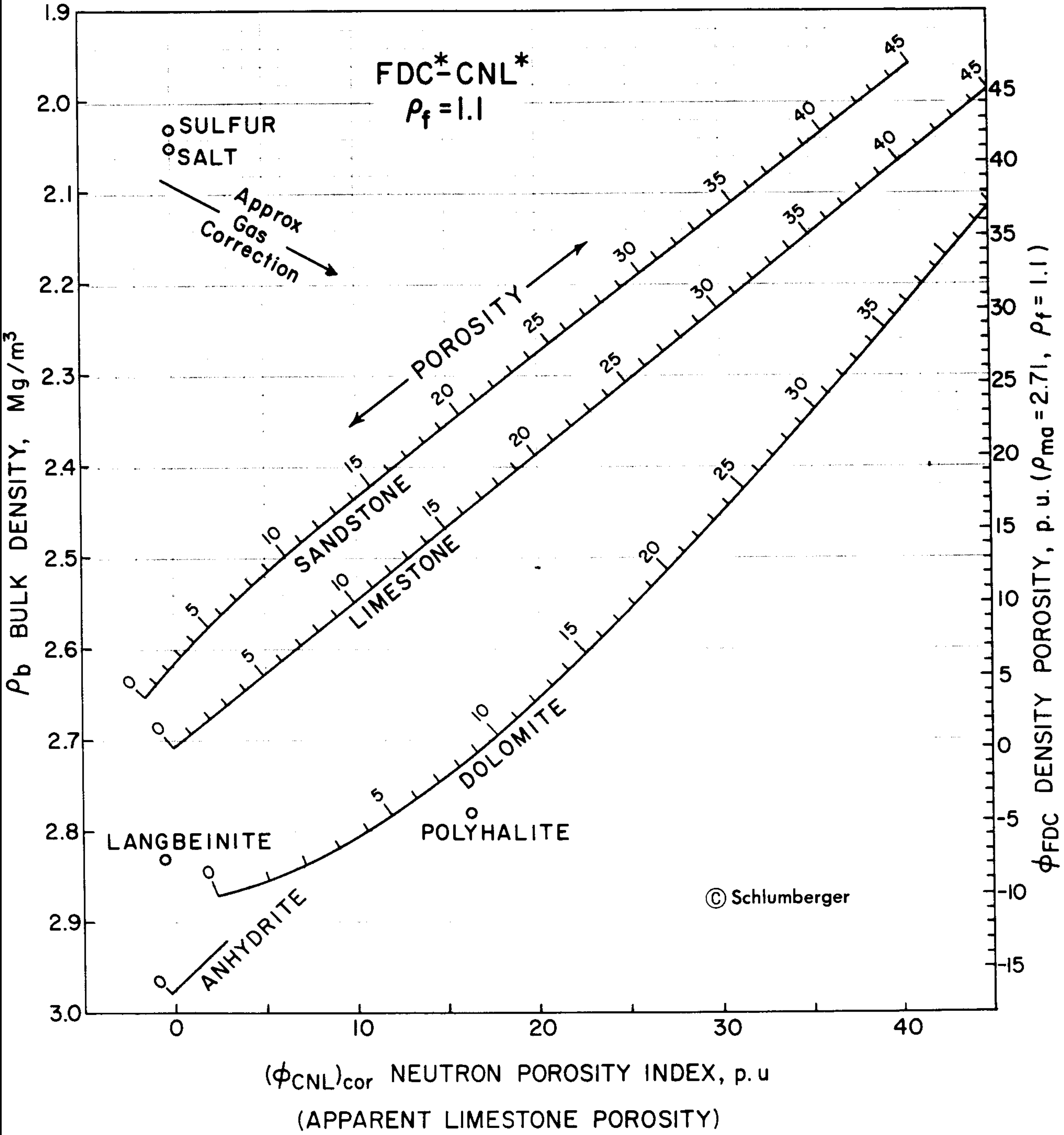




Porosity vs Resistivity.

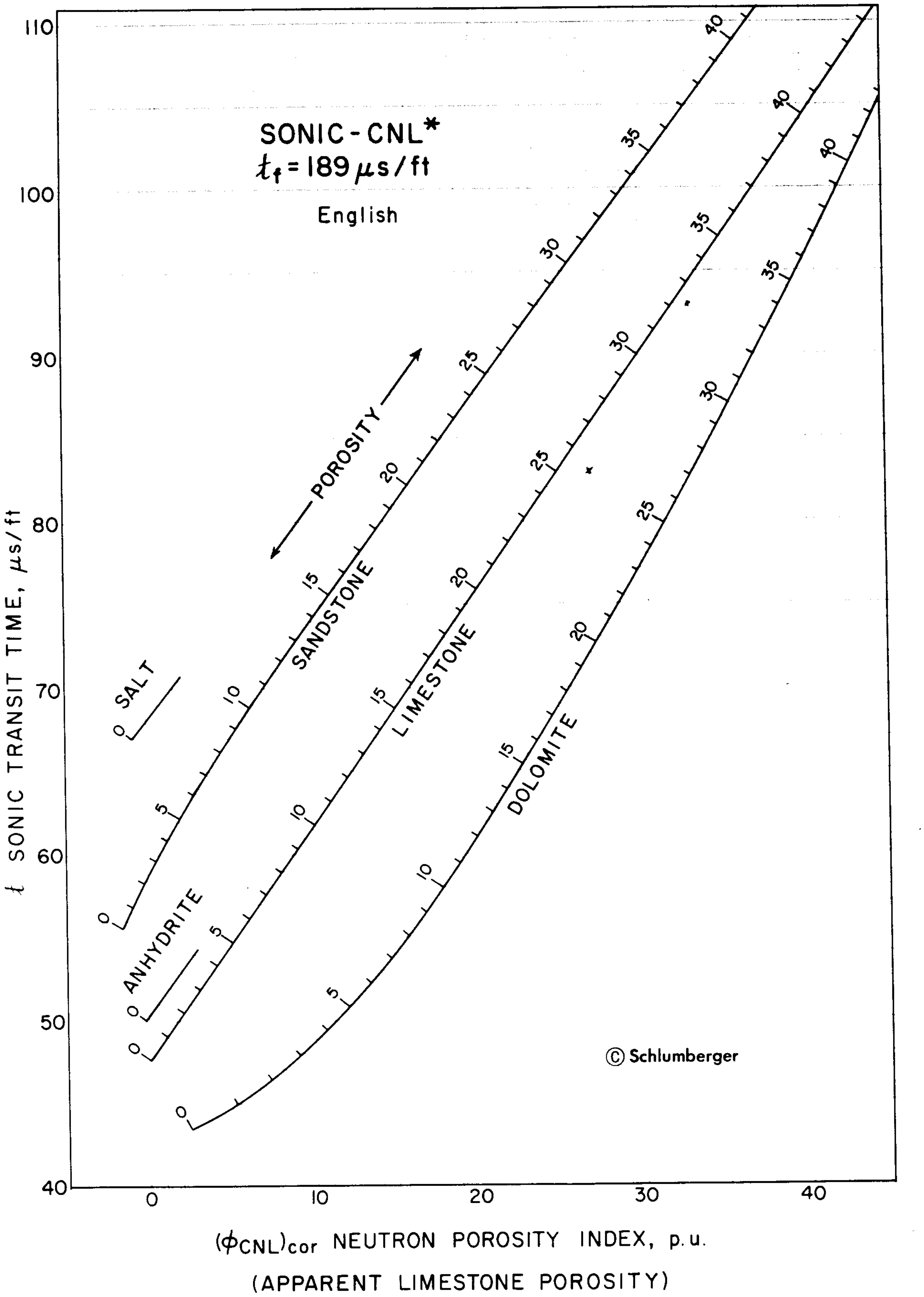
POROSITY AND LITHOLOGY DETERMINATION FROM FORMATION DENSITY LOG AND COMPENSATED NEUTRON LOG (CNL*)

SALT WATER, LIQUID-FILLED HOLES



FDC-CNL-plot

POROSITY AND LITHOLOGY DETERMINATION FROM SONIC LOG AND COMPENSATED NEUTRON LOG (CNL*)



SONIC-CNL plot

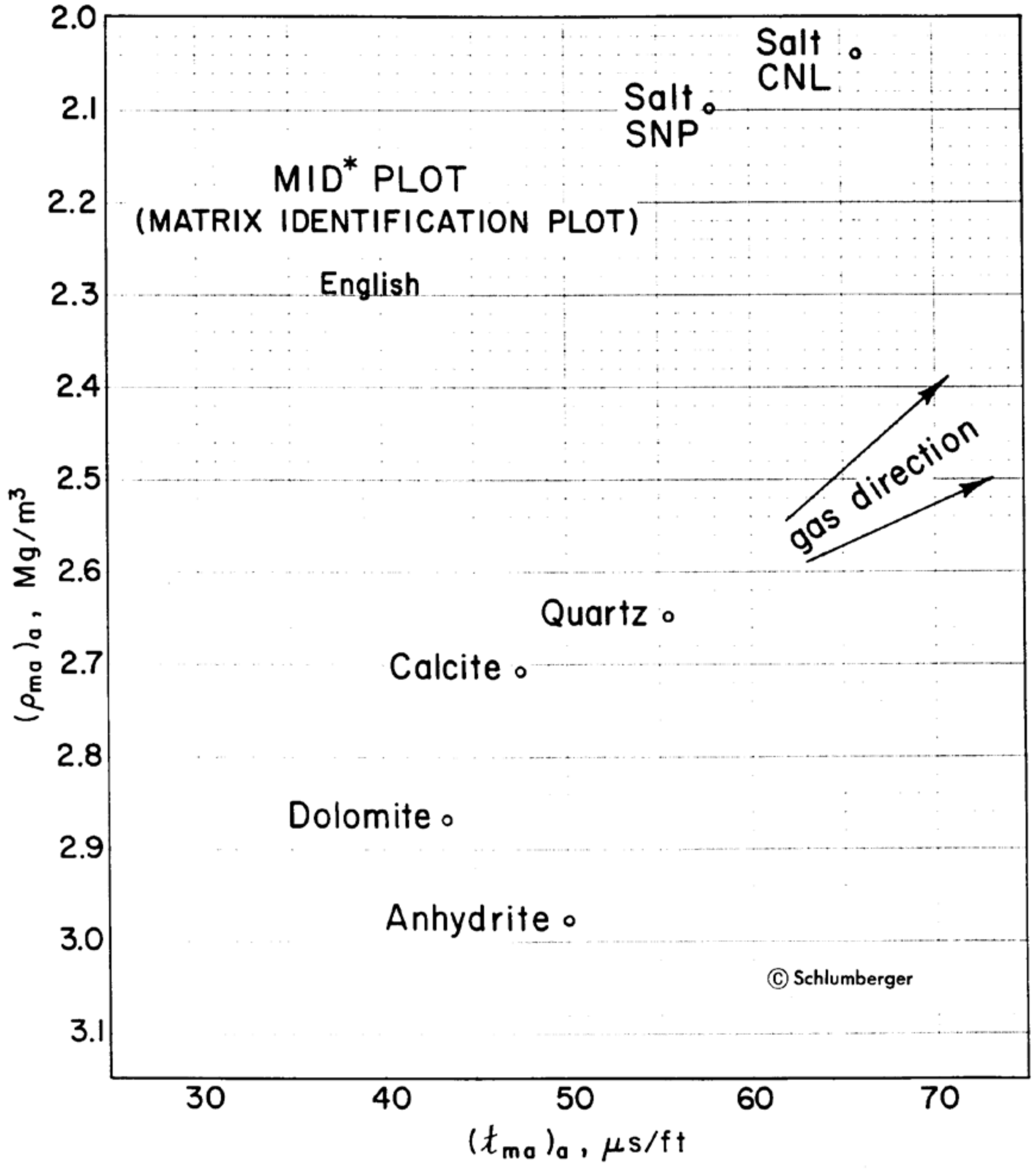
HOW TO USE THE MID PLOT*[8]

Select the $(t_{ma})_a$ and $(\rho_{ma})_a$ charts for your Neutron-log type, borehole-fluid salinity, and measuring system (English or metric).

Tabulate t, and ρ_b, and ϕ_N (limestone) by depths for each chosen station and the resultant $(t_{ma})_a$ and $(\rho_{ma})_a$ from the appropriate chart. Plot the points on the MID-Plot grid. The plot will generally form a pattern which identifies the major reservoir rock by its proximity to the labeled points on the plot.

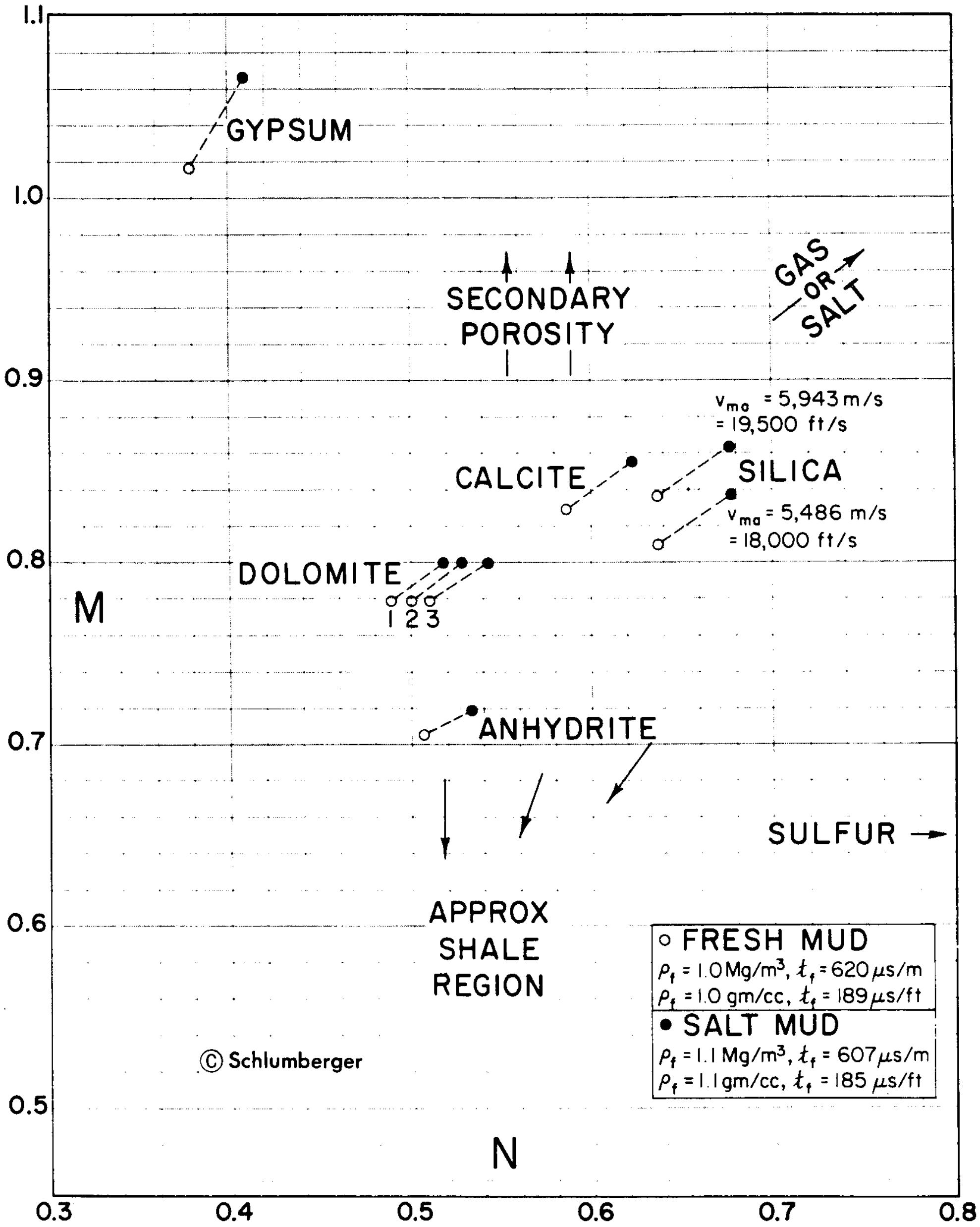
The presence of secondary porosity in the form of vugs or fractures produces displacements parallel to the Sonic-sensitive axis.

The presence of gas will displace points as shown on the basic MID Plot. Identification of shaliness is best done by plotting some shale points to establish the shale trend lines.



MID-plot

M-N PLOT* FOR MINERAL IDENTIFICATION[7]



This crossplot may be used to help identify mineral mixtures from Sonic, Density, and Neutron logs. (The Neutron log used in the above chart is the CNL*.) Except in gas-bearing formations, M and N are practically independent of porosity. They are defined as:

$$M = \frac{t_f - t}{\rho_b - \rho_f} \times 0.01 \text{ (English)}; \qquad M = \frac{t_f - t}{\rho_b - \rho_f} \times 0.003 \text{ (Metric)}; \qquad N = \frac{(\phi_N)_f - \phi_N}{\rho_b - \rho_f} \text{ (Either)}$$

Points for binary mixtures plot along a line connecting the two mineral points. Ternary mixtures plot within the triangle defined by the three constituent minerals. The effect of gas, shaliness, secondary porosity, etc. is to shift data points in the directions shown by the arrows.

The dolomite lines are divided as to porosity as follows:

1) ϕ = 5.5 to 30 p.u. 2) ϕ = 1.5 to 5.5 p.u. and $\phi > 30$ p.u. 3) ϕ = 0 to 1.5 p.u.

M-N plot

EXERCISES 7: A LITHOLOGICAL INTERPRETATION OF COAL AND ITS RELATED SEDIMENTARY ENVIRONMENT WITH THE AID OF COMMON LOGGING TOOLS.

Educational targets: An simple evaluation of several coal seams and related sediments with the results of the natural gamma-ray log, sonic log, neutron-neutron log, and density tool.

Case story:

Due to the lack of "strong" foreign currencies in the Eastern European Countries, the amount of oil and gas, as a major part of the energy supply, is slowly declining. These countries are searching for alternative national energy sources and new ways of energy production. The Bulgaria-coal fields near Rila (Bulgaria) are situated at shallow depths. The area is well known of its relatively small coal fields and thin coal seams. The conventional mining methods are environmentally unacceptable and very expensive. Therefore the Board of the mines decided to investigate alternative coal/energy production methods such as Underground Coal Gasification (UCG) and Coalbed Methane Exploitation (CBM). On the basis of an available exploration well a target area is appraised on its vertical quality. For both methods the thickness of the coal seams (at least 1.5 m) and the sealing quality of overlying strata (claystones or shales) are of major importance.

The following laboratory analysis are known from the exploratory well:

- Several coal seams have been identified.
- The main seam was cored and analyzed on densities:

$\rho_{carb.}$	=	1.20 g/cc	ΔT_{carb}	=	135 Δs/ft
ρ_{ash}	=	2.55 g/cc	ΔT_{ash}	=	80 Δs/ft
ρ_{mois}	=	1.02 g/cc	ΔT_{mois}	=	190 Δs/ft

General questions:

- What are the horizontal and vertical resolutions of the available tools. (Chapter 17, syllabus)
- Give an interpretation of the lithology between 160 m and 215 m, using the gamma ray, sonic and density tools. Square the gamma ray to define layer thicknesses. The following symbols can be used:

: : : : : :	Sandstone/siltstone	####	Claystone/shale
||||||||||||	Carbonaceous claystones	▬	Coal

Questions regarding coal:

- Define the thicknesses of the different coal seams.
- Use figure 2 to define the coal type and ash content. Are the results relevant?
- Calculate the volumes for moisture, ash and coal, based on on the mentioned densities and transit times with the equations 15.2 a,b and c (syllabus)

Questions regarding overburden:

- Use the Gamma ray to define the shale line and sand line.
- Define the shale volumes for the layers in the zone between 160 and 180 m with the GR-shale equation.
- The clean sands in this section show an increasing transit time. What are the porosities when a Sw=1 is considered? (use the bulk density, ρ_{mois}=1.02 g/cc and ρ_{matrix}= 2.68 g/cc).

Conclusive question:

- Which coal seam can be used for UCG or CBM?

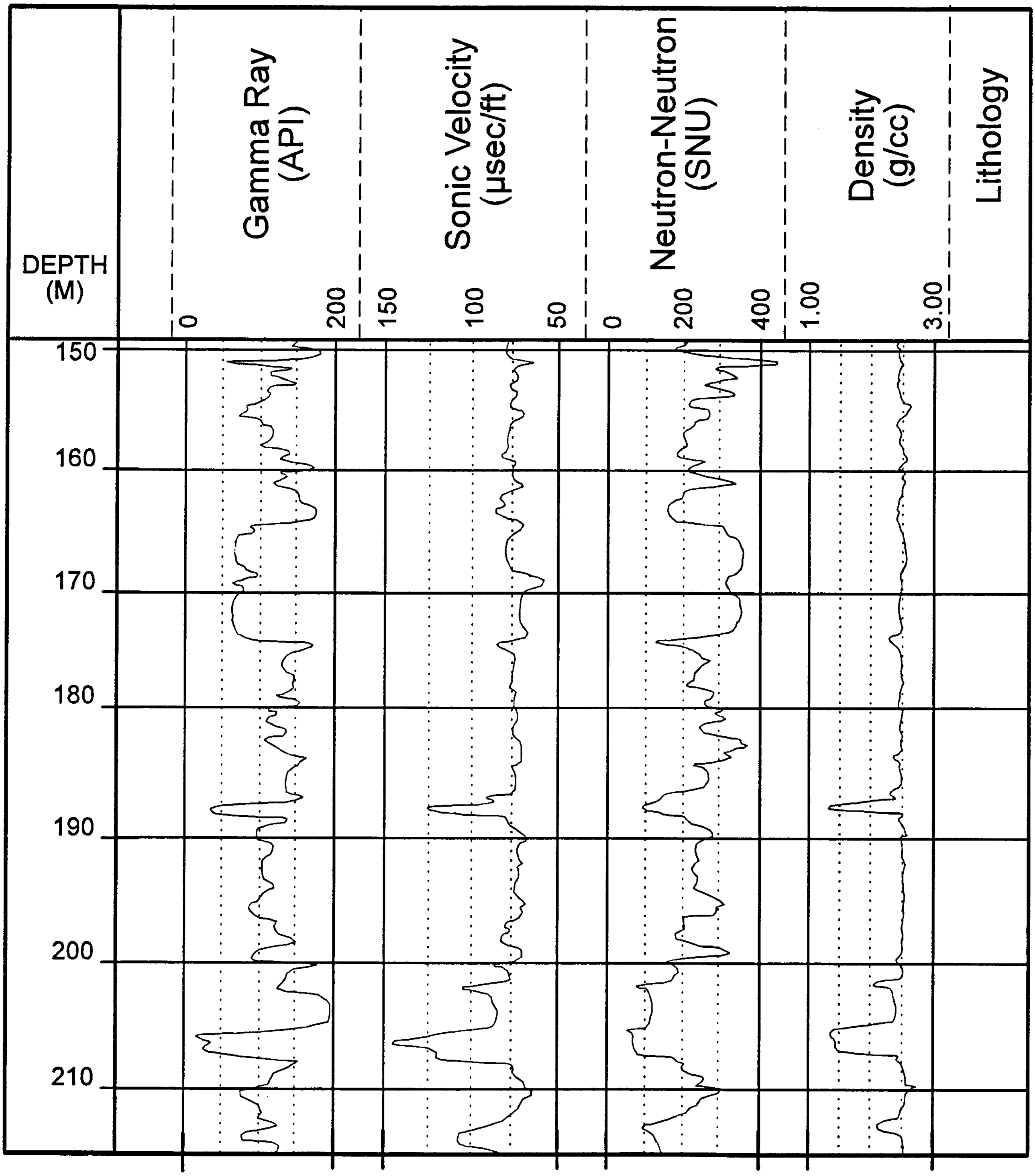
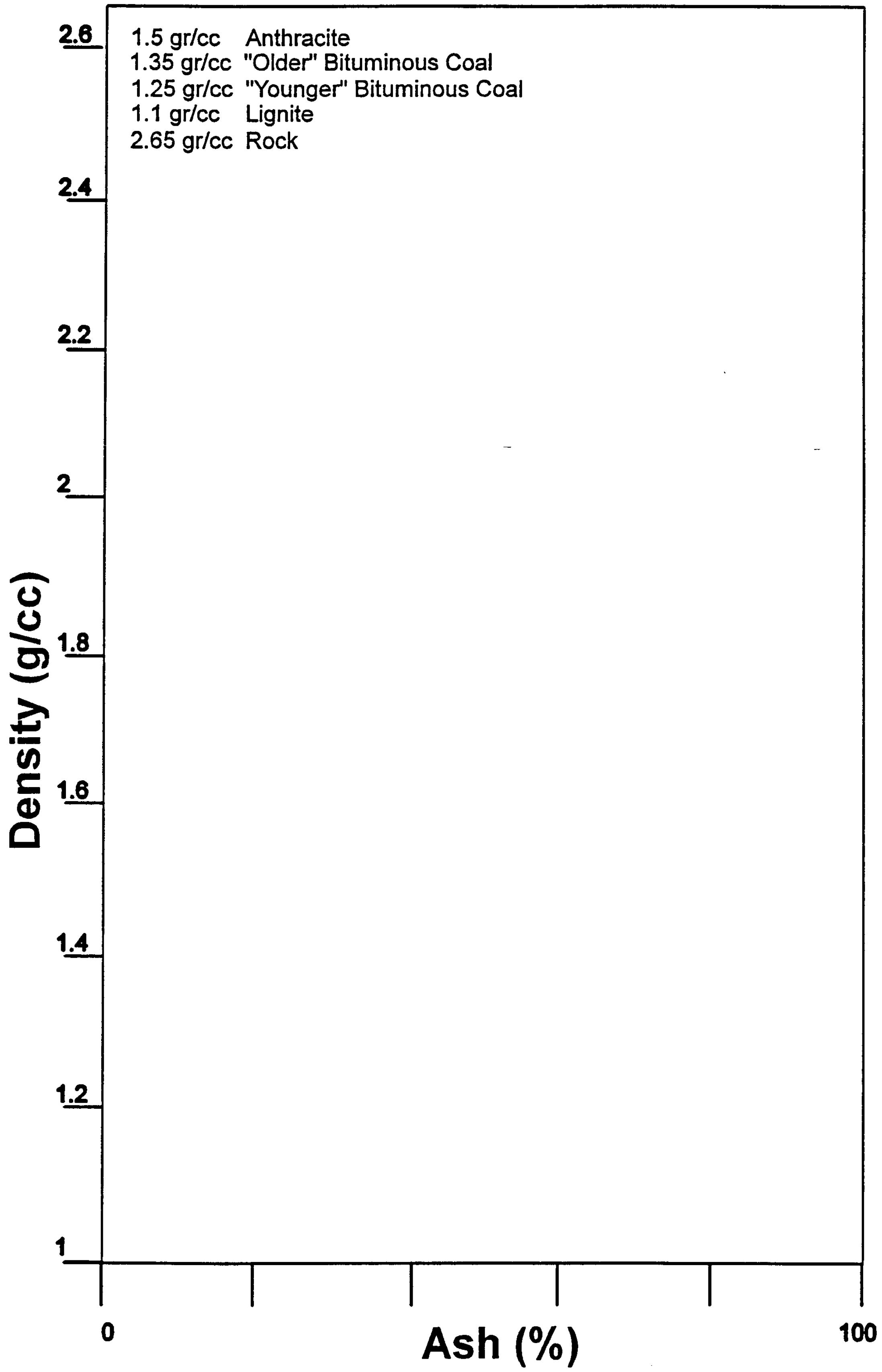

DEPTH (M)
Gamma Ray (API)
0
200
Sonic Velocity (µsec/ft)
150
100
50
Neutron-Neutron (SNU)
0
200
400
Density (g/cc)
1.00
3.00
Lithology
150
160
170
180
190
200
210

FIGURE 2: COAL DENSITY VS ASH CONTENT



EXERCISES 8: INTERPRETATION OF WATER BEARING STRATA OR POTENTIAL AQUIFERS AND THE EVALUATION OF THE RELATED SEDIMENTARY ENVIRONMENT WITH VARIOUS LOGS

Educational targets: An simplified evaluation of water bearing strata and related sediments with the results of the SP-, resistivity- and natural gamma-ray measurements.

Related theory: Ground-water log evaluation.

Case story:

In Northern China, the Mongolian area is developing to a new tourist region. In order to acquire the blessings of the foreign currencies, the area has to conform to western standards, i.e. hotel, food and drinking facilities. Water is a major concern since the area is considered to be an arid area, just south of the the Gobi desert. An old spring is planned to be used as the source for the new Gobi Hilton Hotel. Both fresh and salt water have been found in an appraisal well. The fresh water part will be used for consumption, the salt water for clinical purposes (Thermae Hilton).

Questions regarding the log interpretations:

- Define the aquifer positions with the aid of the available logs.
- Use figure 1 to place the filter beds.
- Define the transition between the fresh and salt water zones; Where will you place your permanent electrodes to monitor the water salinity?

Questions regarding water production:

The transition zone (figure 2A,B) shows a mix of fresh and salt water. Pumping tests of this zone showed a flow rate of about 60 m^3/hr.

- Define the productive zones (aquifers)
- Define the amount of salt water and fresh water that is produced according to the pumping test.

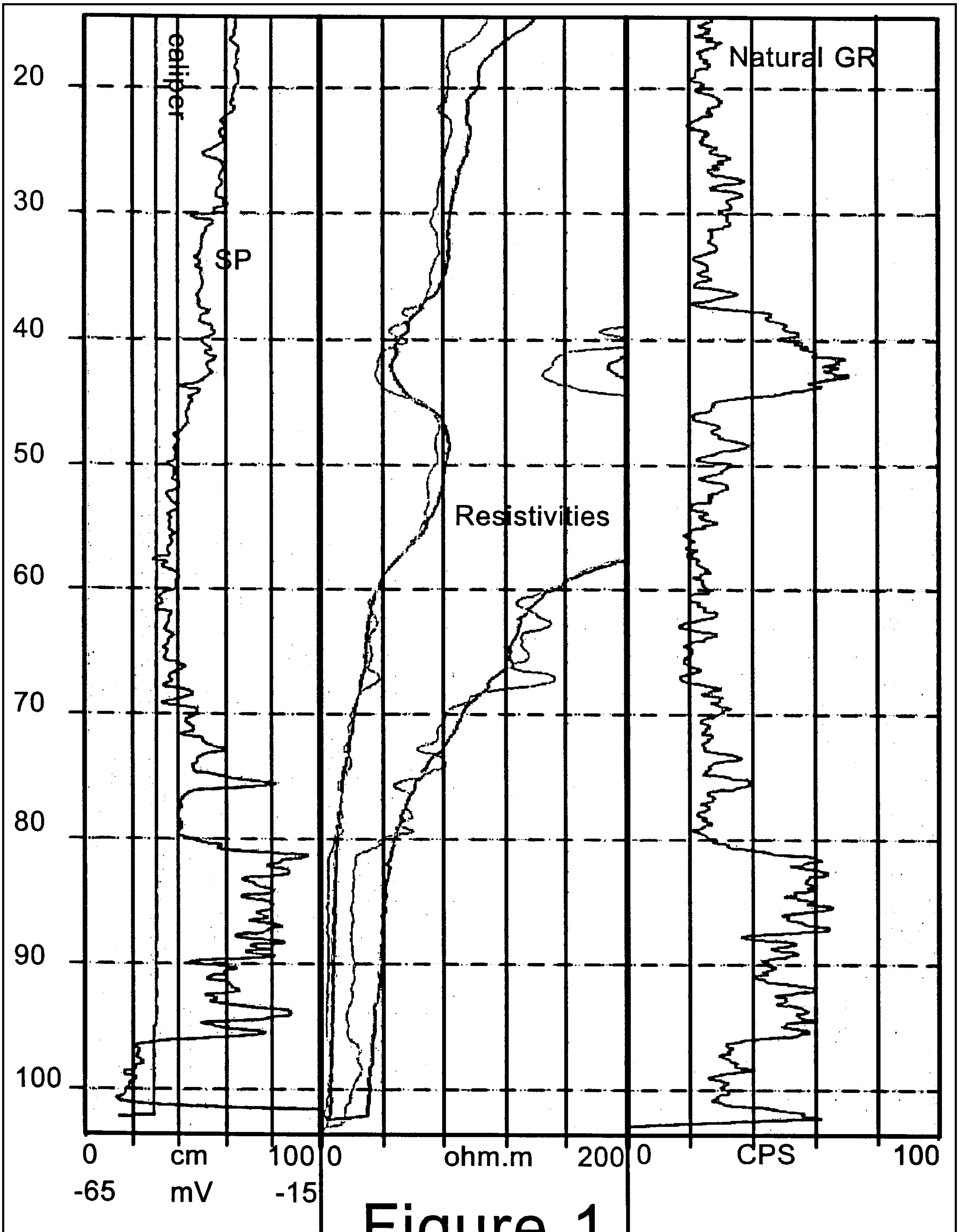

caliper
SP
Resistivities
Natural GR
20
30
40
50
60
70
80
90
100
0
cm
100
-65
mV
-15
0
ohm.m
200
0
CPS
100

Figure 1

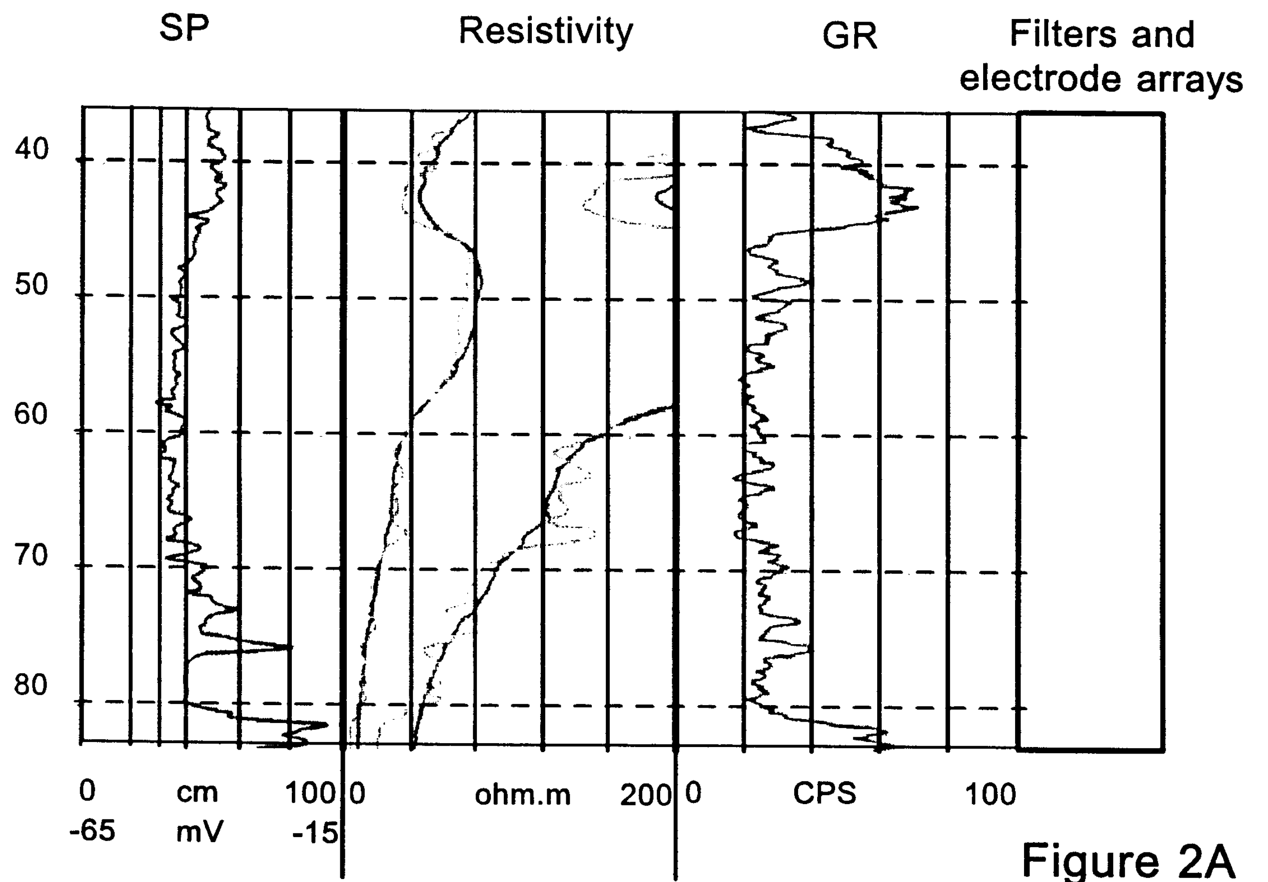


Figure 2A

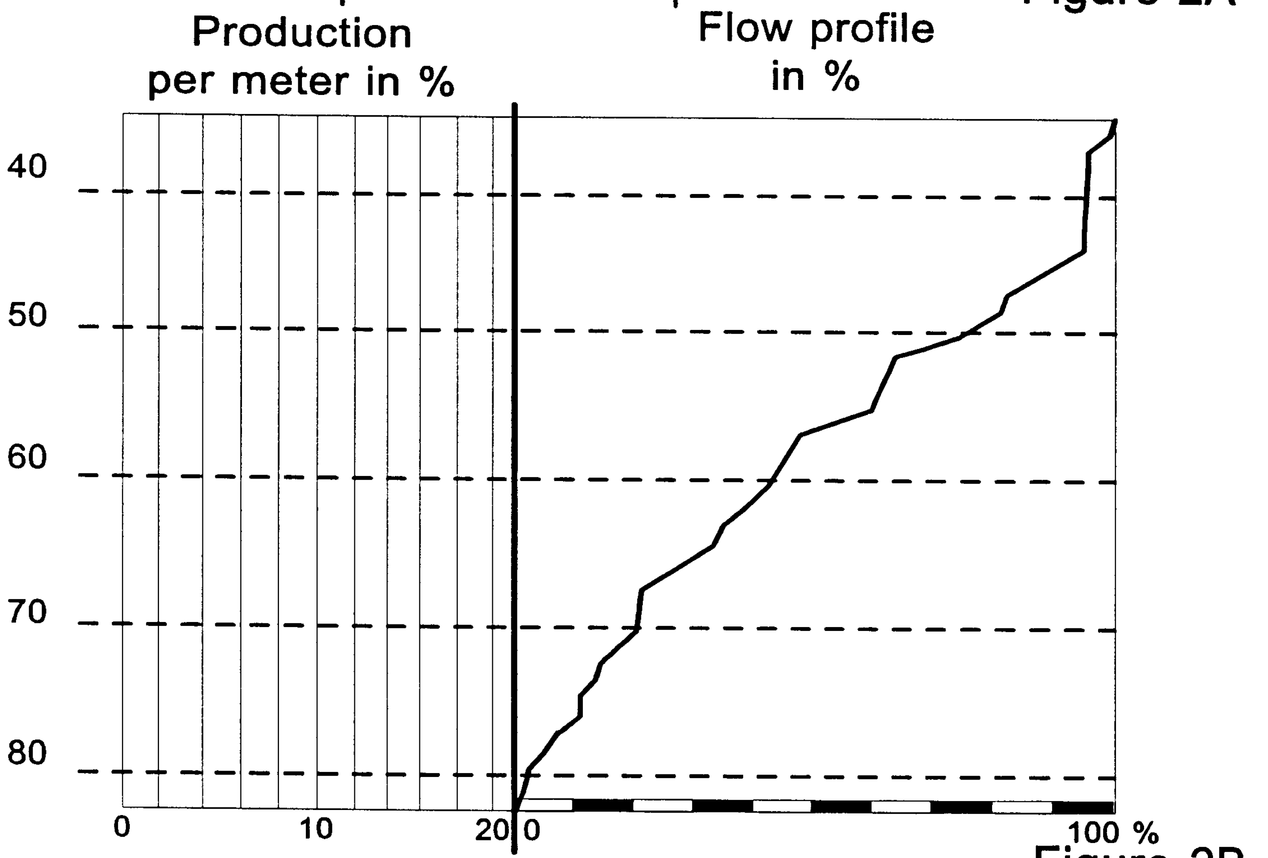


Figure 2B

EXTRA EXERCISE: SP MEASUREMENTS WITH COMPENSATIONS FOR THE PRESENCE OF SHALE (WHEN DISCUSSED IN THE LECTURES)

Principle use for:

- Bed boundary definition.
- Recognition of reservoir (oil, gas, coal, ore, water etc.) versus non-reservoir.
- Determination of shale volume (Vshale).
- Formation water resistivity determination.
- Correlation between exploration holes.
- The environment of deposition.

Marakesh, a North African city is confronted with a serious shortage on electrical capacity. Since transportation of fresh water for cooling purposes (for a new power plant) will be to expensive, alternative sources have to be utilized. This part of the Sahara desert contains numerous water bearing sandstone members. Since the quality of the water (salinity) will be important for the technical development of the cooling equipment, several exploration drilling were completed. Thereafter logging measurements (GR, Caliper, Temperature and SP) were done to define the stratigraphy and the water quality. According to the Delft Petrophysical Section of the Mining Department, three wells seemed to be prospective..

Determine the salinity and resistivity (Rw at FT) of the formation water in the three wells. (an example is given in chapter 8 of the college notes.)

Well 1:

Log results	:	SP = -42 mV; Ekmc = -6 mV, Qv(shale) = 4 meq/cm^3 .
Mud	:	Density 72 lbs/cuft, Rm = 1.6 ohm.m at 90˚F, Rmf = 1.0 ohm.m at 90˚F
Formation	:	Very thick (120 m), clean, unconsolidated, low resistive water Sand (0.015 ohm.m). Shallow invasion: di/dh < 2 Formation pressure 3550 psi. FT = 195˚F, Rs = Rm
Hole	:	Depth 7500 ft, size 9 5/8 "

Well 2:

Log results	:	SP = -25 mV; Ekmc = -10 mV.
Mud	:	Density 9.5 lbs/gal, Rm = 0.9 ohm.m at 77 F, Rmf = 0.7 ohm.m at 77˚F
Formation	:	Alternating 10' beds of shale and shaly sands. Rs = 2 ohm.m; Rt = 20 ohm.m. Qv(sand) = 0.2 meq/cm^3, Qv(shale) = 4 meq/cm^3 Shallow invasion: di/dh < 2 Formation pressure gradient 0.44 psi/ft FT 145˚F
Hole	:	Depth 5500 ft, size 9 5/8 inch.

Well 3:

Log results	:	SP = +13 mV; Ekmc = -4 mV.
Mud	:	Density 72 lbs/cuft, Rm = 0.5 ohm.m at 77˚F, Rmf = 0.3 ohm.m at 77˚F
Formation	:	Thickness 20 ft, shaly sand. Rs = 1 ohm.m; Rt = 20 ohm.m Qv(sand) = 0.3 meq/cm^3; Qv(shale) = 4 meq/cm^3 Shallow invasion: di/dh = 2 Formation pressure gradient 0.44 psi/ft. FT = 180˚F
Hole	:	Depth 5000 ft, size 6".

Explanatory notes

Conversions: 100 lb/cuft = 1.6 g/cm^3, 10 lb/gal = 1.2 g/cm^3, (1') or 1 ft = 0.3048 m, (1") or 1 inch = 2.54 cm, 1 atm. = 14.3 psi.

Symbols**:**

h	**-**	**Layer thickness on the location where the SP is recorded.**
d	**-**	**Borehole diameter.**
Rs	**-**	**Resistivity of the layer above and below the considered layer h.**
Rm	**-**	**Mud resistivity.**
Rt	**-**	**True virgin resistivity of the considered layer h.**
Rw	**-**	**Formation water resistivity of the considered layer h.**
Pm	**-**	**Mud pressure in the borehole.**
Pf	**-**	**Fluid pressure in the reservoir of layer h.**
P	**-**	**Pressure difference (Pm-Pf)**

Complete the tables with the help of the example in chapter 8 of the college notes and the specified information of the exploratory wells.

		Well 1	Well 2	Well 3
SSP	**SP in mV**			
	h/dh	>40		
	Rs/Rm	1		
	Rt/Rm			
	SP/SSP			
	SSP in mV			

Ekmc	**Given in mV**			

Eksh	**Pm in psi**			
	Pf in psi			
	P in psi			
	Eksh in mV			

Ec at 77˚	**SSP in mV**			
	Ekmc in mV			
	Eksh in mV			
	Ec at FT in mV			
	Ec at 77˚ in mV			

Qv	**Given**			

NaCl mud filtrate in g/l			
NaCl formation water in g/l			
Rw at FT in Ohm.m			