出國報告（出國類別：實習）

參加 PetroSkills
舉辦之井測解釋訓練課程
（Well Log Interpretation）

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派赴國家：美國
出國期間：104 年 12 月 06 日至 12 月 13 日
報告日期：104 年 12 月 21 日

參加 PetroSkills 舉辦之井測解釋訓練課程

摘　要

104 年度石油基金「南海北坡靖海凹陷石油地質評估」計畫編列派員出國計畫，井測解釋分析為石油公司相當重要且為最普遍常見的應用技術之一。因台灣西南海域岩性變化複雜，且位於海域其鑽井費用昂貴，為能充分整合並應用儲集岩各種地質、岩石物理、流體資料等，乃參與本訓練課程，藉以提升公司此項應用技術。

學習並建立新的井測解釋技術，並整合其餘地質、鑽井工程等資料分析儲集岩孔隙率、滲透率、水飽和度等物理性質，及儲集岩與流體特性間可能造成之問題，降低國內外礦區評估與生產技術風險。

同時藉由此次參與國際會議的機會與會中國外專家學者進行技術交流以及經驗交換，成果可直接應用於本公司查德或未來其他油氣田之生產開發工作。

Tight

Fracture

關鍵詞：

參加 PetroSkills 舉辦之井測解釋訓練課程

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壹、目的

參加 PetroSkills 國際石油訓練機構舉辦之井測解釋訓練課程（Well Log Interpretation）為期 5 天(圖一)，學習利用各種地質、井下電測等資料，並研習不同井測儀器的原理與應用，進而整合分析儲集岩岩石物理特性。

內容主要包含(圖二)：1、不同井測測量工具的原理與應用，包含 GR、Sonic 等。2、利用岩石孔隙、滲透、流體特性等電測資料之整合分析各種儲集岩物理特性，藉以了解儲集岩分布特性，降低探勘風險。3、了解井測解釋上的不確定性與可能誤差。

藉此充分整合與應用不同儲集岩特性與其地質、岩石物理、流體特性等資料，並經由課程實際操作，加強井測解釋技術，此將有助於提升本公司現行礦區評估方法，降低未來國內外礦區評估風險。

貳、過程

本次出國行程如下所示：

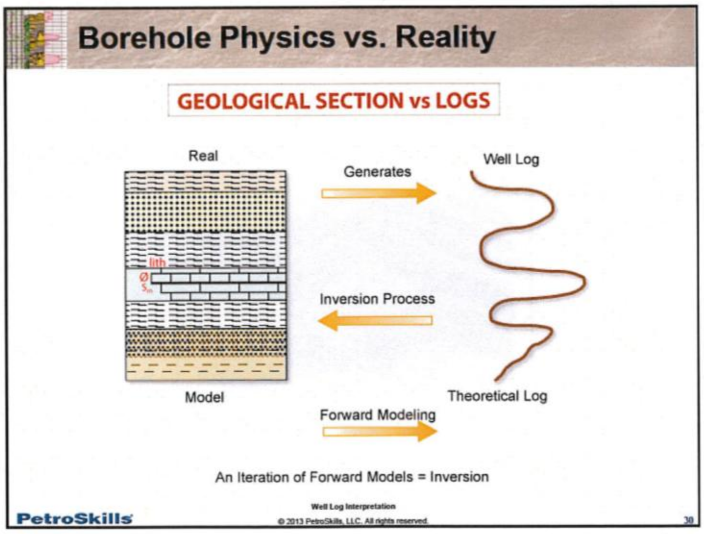
12月6日：啟程(台北－休士頓, Houston)

12月7日：Temperature gradient, Resistivity, SP

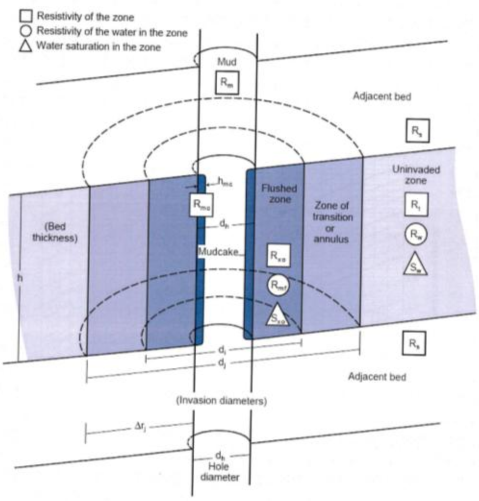
COURSE AGENDA

WELL LOG INTERPRETATION

			Manual	Exercises
Day 1				
A.M.	Intro	Logging objectives and borehole environment	Section i	
	1.	Passive electrical properties of earth materials	Section1	1-3
	2.	Resistivity logging	Section 2	2-4
P.M	3.	Spontaneous potential	Section 3	3-3
	4.	Matrix-sensitive logs: Gamma Ray	Section 4	4-13+
Day 2				
A.M.	5.	Depth measurement and control	Section 5	
	6.	Borehole calipers	Section 6	
	7.	Porosity-mineralogy logs	Section 7	2-4
	8.	Porosity determination	Section 8	2-4
P.M.	9.	Identification of mineralogy	Section 9	9-3+
	10.	Energy spectrum radioactivity logs	Section 10	10-13+
Day 3				
A.M.	11.	Formation resistivity factor	Section 11	11-3
	12.	Conductivity of shales	Section 12	
	13.	Water resistivity determination	Section 13	2-4
P.M.	14.	Saturation determination	Section 14	2-4
	15.	Reconnaissance and quicklook techniques	Section 15	2-4
	16.	Porosity-resistivity crossplots	Section 16	2-4
Day 4				
A.M.	17.	Permeability by logging methods	Section 17	chart K-3
	18.	Reservoir delineation by pressure measurements	Section 18	18-3+
P.M.	19.	Nuclear magnetic resonance NMR	Section 19	19-3
	20.	Log analysis by computer	Section 20	
Day 5				
A.M.	21.	Sidewall coring	Section 21	
	22.	Logging while drilling	Section 22	
	23.	Recommended logging programs	Section 23	
	24.	Comprehensive exercise 3-7		3-7



Symbols used in Log Interpretation



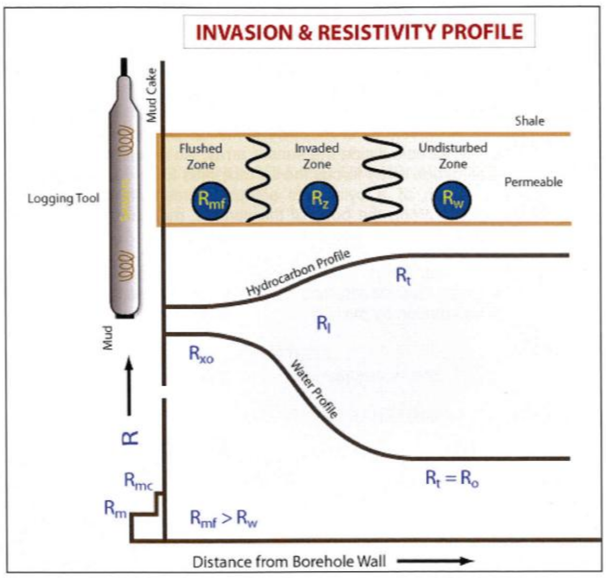


Figure i.4.1. The effects of invasion of mud filtrate in a permeable zone and the resultant resistivity profile.

Day 1 Exercise

1. To calculate temperature gradient, Bottom Hole temperature, surface temperature and TVD must be known.

EXERCISE 1 – 3 Suggested Solution

1. During logging, the bottom hole temperature of a newly drilled well, as measured by a maximum-reading thermometer was 255°F. Total depth of the well, as measured by the logging cable, was 14,365 feet. The mean surface temperature was about 70°F. A formation at 9,820 feet required analysis. What value of temperature should be used?

   Calculate geothermal gradient G:

   $$G = \frac{255 - 70}{14365 \times 0.01} = 1.288°F/100\,ft$$

   Calculate formation temperature BHT at 9820 ft:

   $$BHT = 70 + 1.288 \times \frac{9820}{100} = 196.5°F$$

2. A sample of the drilling mud filtrate was measured at the surface and was found to have a resistivity of 1.48 Ωm. The temperature of the mud filtrate sample when it was measured was 90°F. What value of mud filtrate resistivity should be used in the analysis of the zone at 9,820 feet?

   $$Rmf2 = Rmf1 \times \frac{T1 + 6.77}{T2 + 6.77} = 1.48 \times \frac{90 + 6.77}{196.5 + 6.77} = 0.704\Omega m$$

   Salinity from Schlumberger Chart Gen-9: 3,000 ppm NaCl equiv.

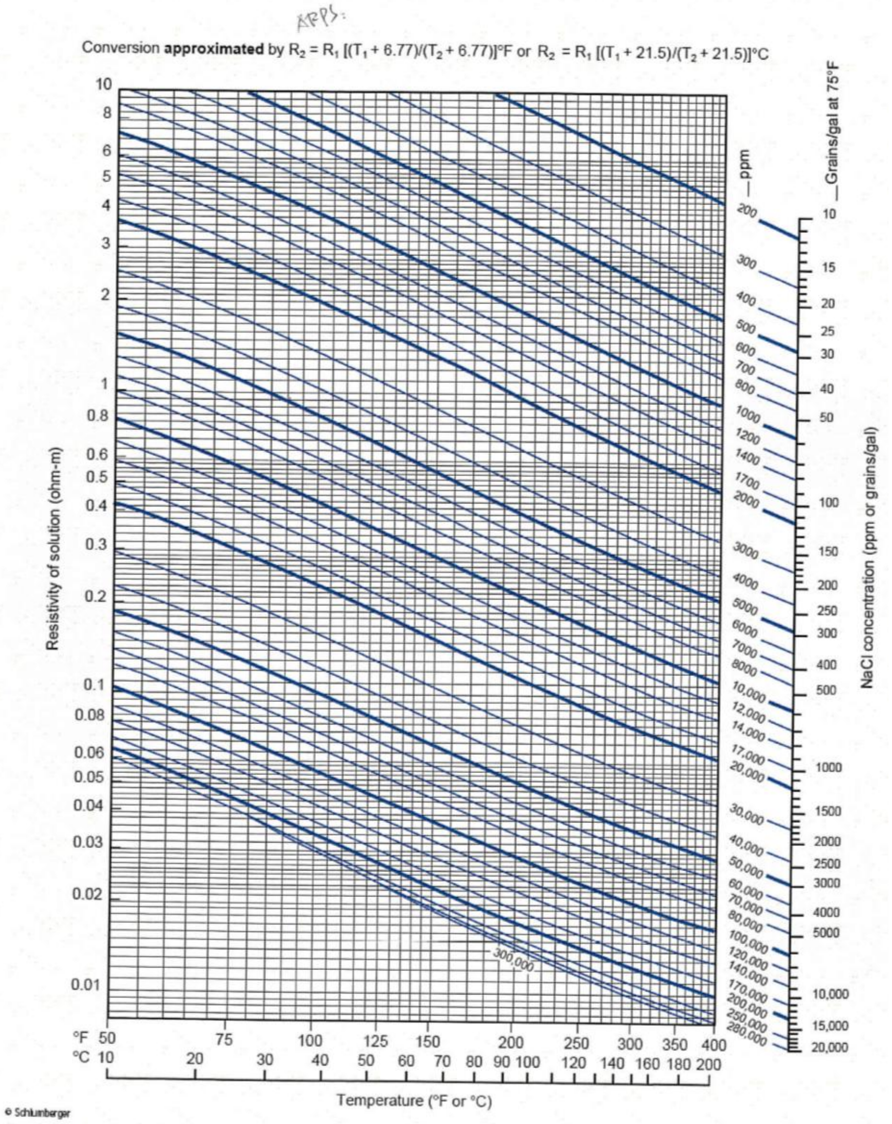
3. A good produced water sample from this same formation was available from a nearby well, which had encountered this formation structurally lower. Surface resistivity measurements indicated Rw = 0.12 Ωm @ 72°F. What would be the resistivity of this water at formation depth, i.e., at 9820 feet?

   $$Rw2 = Rw1 \times \frac{T1 + 6.77}{T2 + 6.77} = 0.12 \times \frac{72 + 6.77}{196.5 + 6.77} = 0.046\Omega m$$

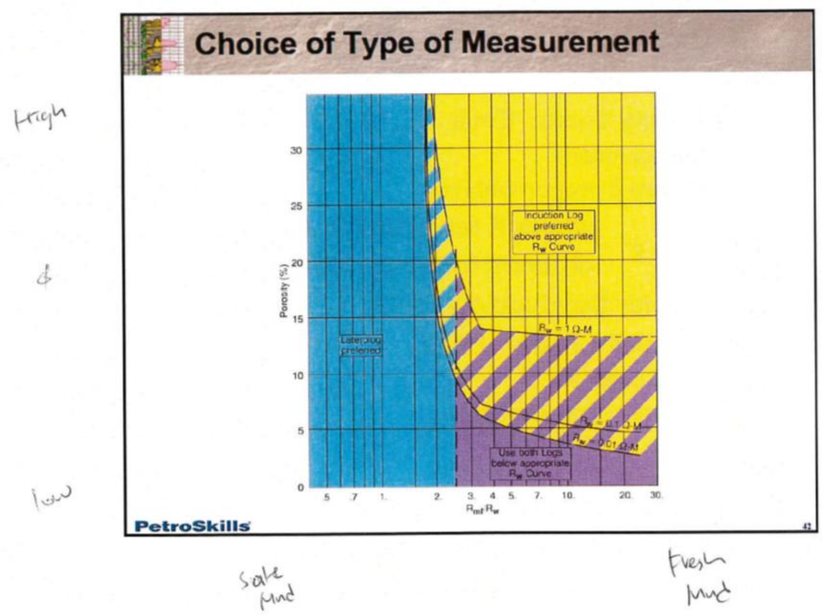
   Salinity from Schlumberger Chart Gen-9: 60,000 ppm NaCl equiv.

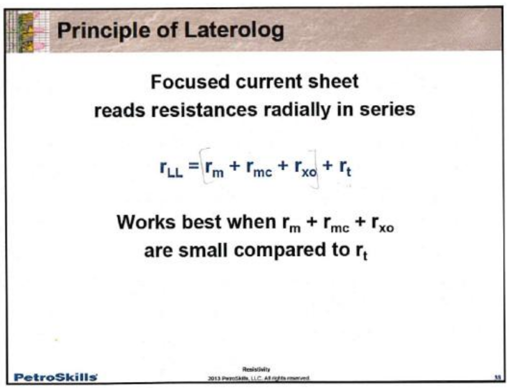
2. An understanding of formation temperature is important because <u>resistivity changes</u> (impacts resistivity of fluids R_{mf}, R_w).

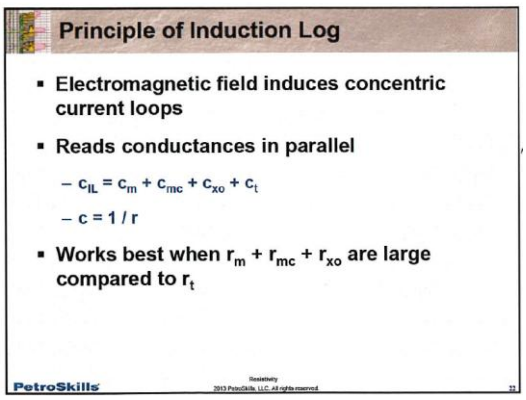
Resistivity of NaCl Solutions



3. Induction logs measures conductivity and are well suited for fresh water resistivity (or OBM) borehole fluids and low-medium (400-500 ohm meter, Ωm) resistivity.
4. Laterologs measure resistivity and are well suited for conductive resistivity (or salt mud) borehole fluids and medium-high (2000 Ωm) resistivity.



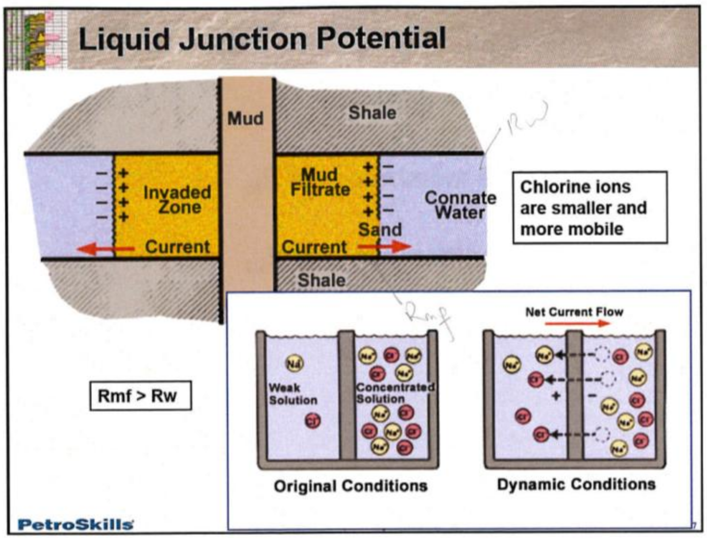


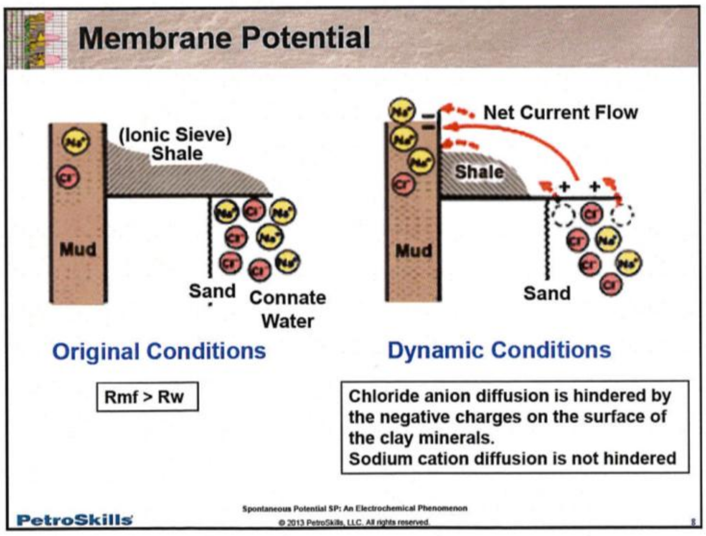


5. The two primary potentials that create the SP are membrane and liquid Junction.

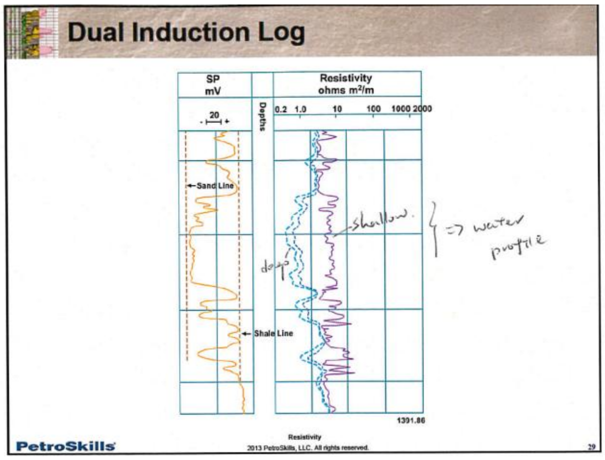
6. What 3 conditions must be present for an SP to develop?

Conductive borehole fluid, $R_{mf} \neq R_w$, Shale, permeable formation and borehole co-exist.



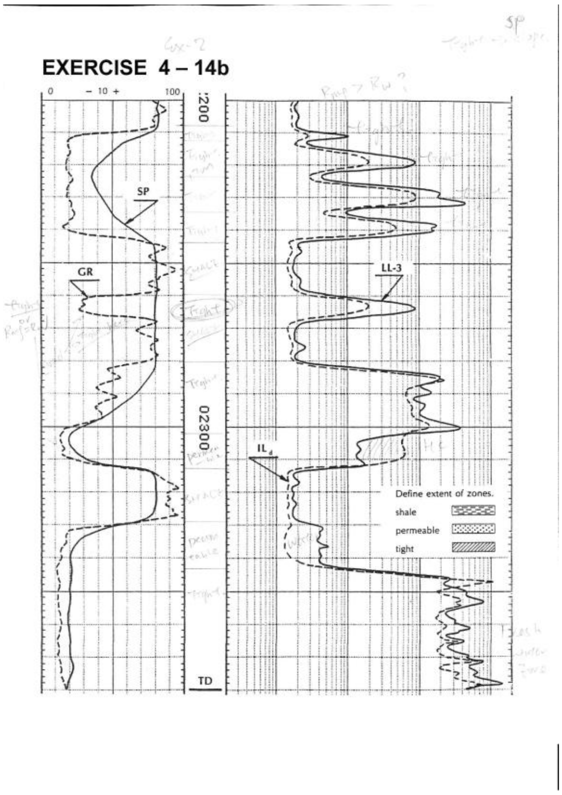


7. Separation among resistivity curves indicates permeable formation (Invasion), which implies <u>sand exist (or permeable formation)</u>.



8. In tight formation, which types of resistivity log signature would be expected?

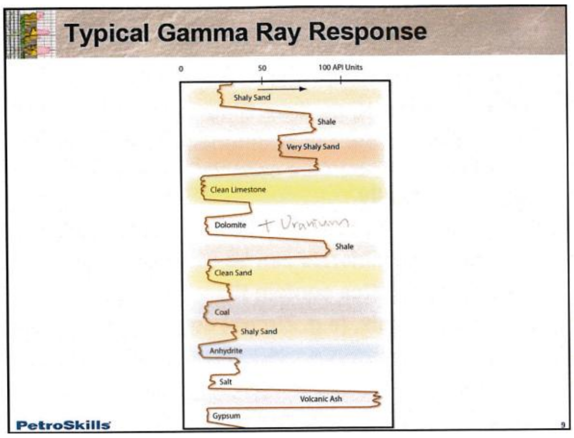
<u>High resistivity</u>, <u>little to NO separation</u>.



12月8日 ：Gamma Ray log, Calipers, Porosity (Density Neutron and velocity log)

Day 2 Exercise

1. The Gamma ray measures natural radioactivity from Potassium (K), Uranium (U), and Thorium (Th).

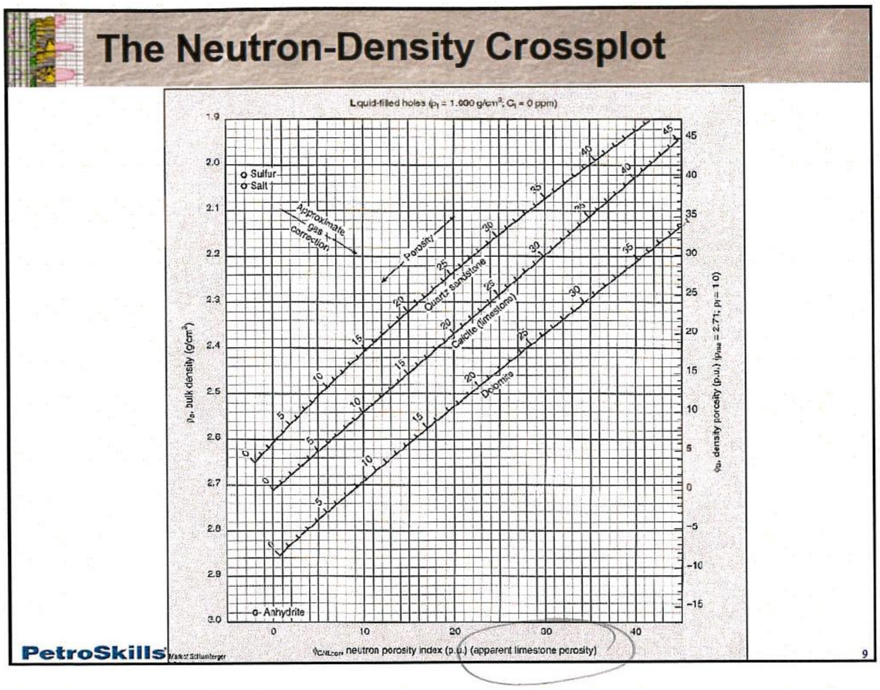


2. The Gamma ray log can be used to differentiate shale from conventional reservoirs with some exceptions ex. Dolomite (U), fractures (U), Glauconite (K), Granite wash (K), Mica (K), Kaolinite (w/o K, U, Th).
3. The density log measures Gammy ray counts per second from which electron density is determined, which is calibrated in limestone and converted to bulk density with which porosity can be calculated.
4. The neutron log is essentially a log of hydrogen of reservoir.
5. In a gas reservoir, the reason of neutron porosity is low and density is high? Neutron porosity: hydrogen index of CH_4 molecule is low compared with H_2O and fluid density is underestimated.
6. The two primary wave types of interest in sonic loggings are compression and shear. Fastest is compression.
7. Why is it difficult to compare acoustic properties from core, logs seismic? Scale of measurement.
8. When calculating porosity from a single device matrix density, fluid density must be known or assumed.

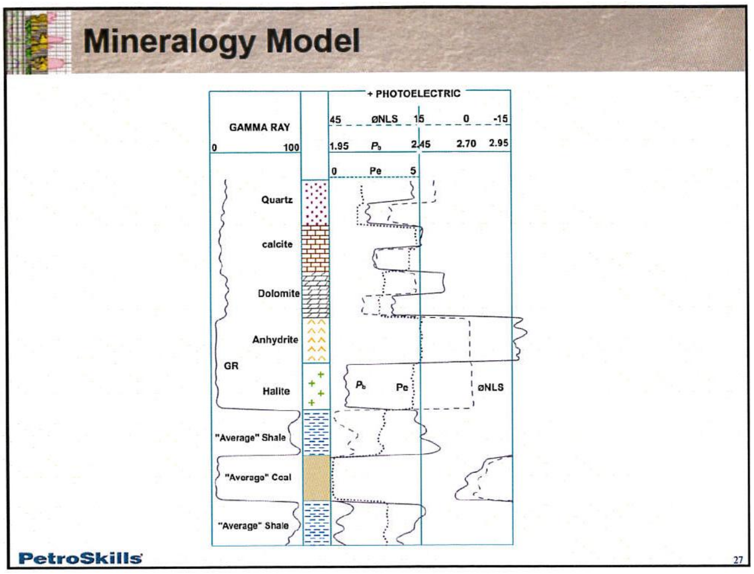
12月9日: Minerology

Day 3 Exercise

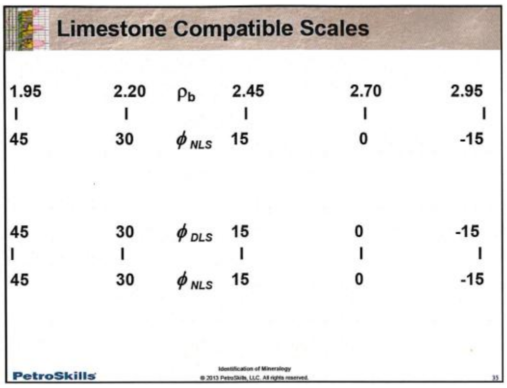
1. Using two porosity device porosity and minerology can be determined and perhaps an indication of Fluid type or Gas.
2. Comparison of density porosity and neutron porosity can be useful in identifying secondary porosity

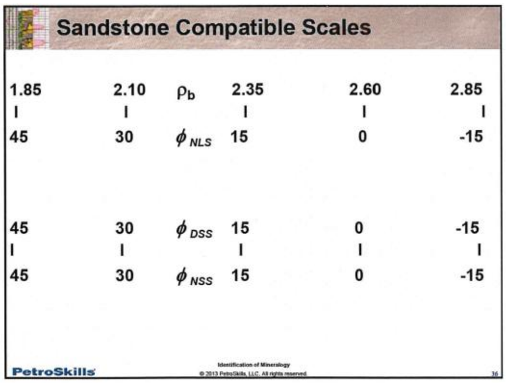


3. Pe (Photoelectric absorption) Curves is a lithology indicator relatively insensitive to porosity and Fluids(Gas); calcite: 5.08, Quartz: 1.81; Dolomite: 3.14



4. Before doing quick look mineralogy identification, it is important to ensure compatible scale.

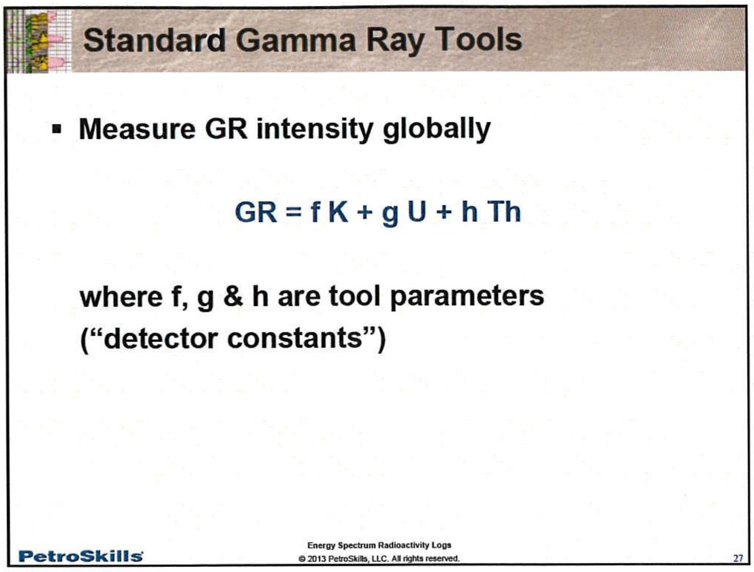




5. To solve for 3 minerals cross-plot of apparent matrix grain density vs apparent Time AND apparent matrix volumetric photoelectric factor vs apparent matrix grain density can be useful.

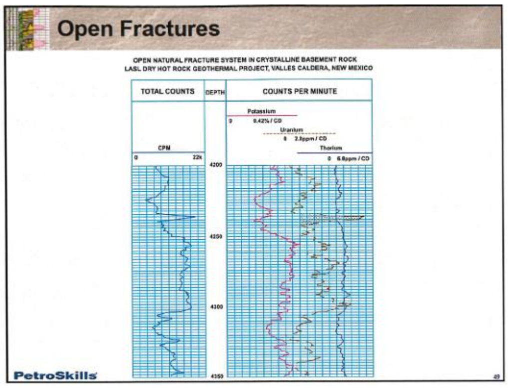
6. Thick Barite mud cake cause issues with Pe curve data.

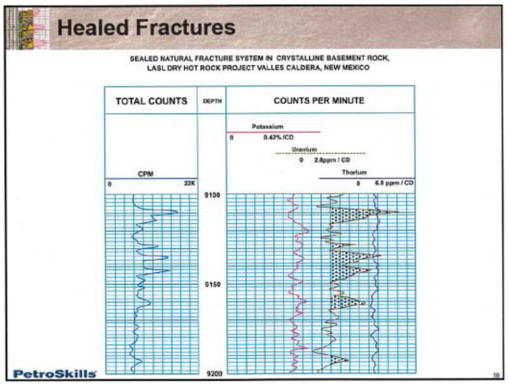
7. Spectral Gamma ray tool differentiate Gr from L U Th. Some application are fractures (U), dolomite vs shale (U), unconform (Th), Source rock potential (T), correlation (K/Th), V shale(remove K)(micaleous feldspar)



8. If you are asked to identify fracture, organic rick shales what are some log responses you might investigate?

   (1) High Uranium. (2)U spikes, (3) Heavy Mud (Barite) from Pe (Photoelectric absorption) spike (4) Correction rho (5) Spiky caliper (6) High resistivity or high porosity



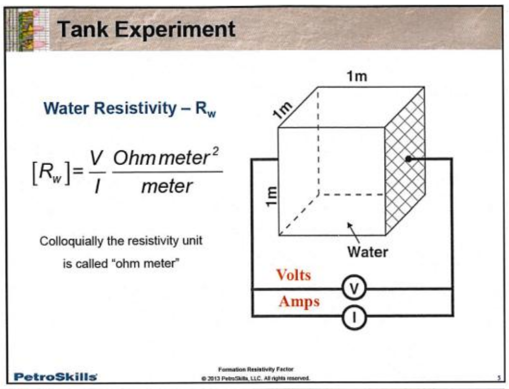


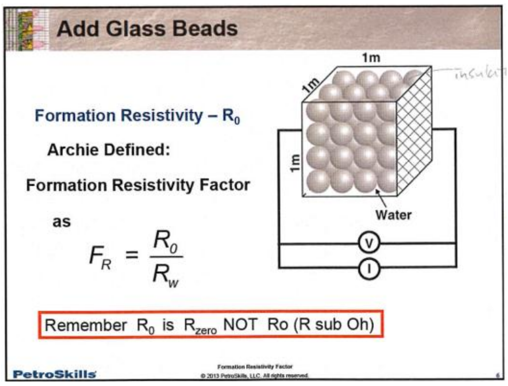
Density log is on the left hand side. Uranium log is on the right hand side with spike

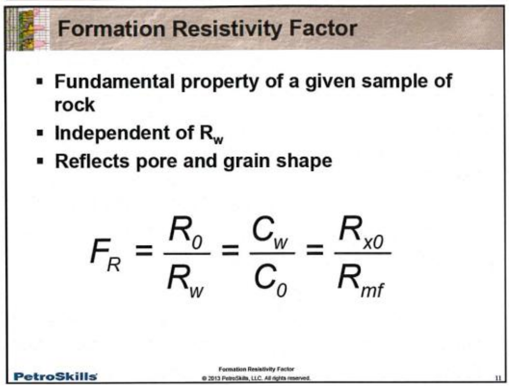
12月10日: Saturation

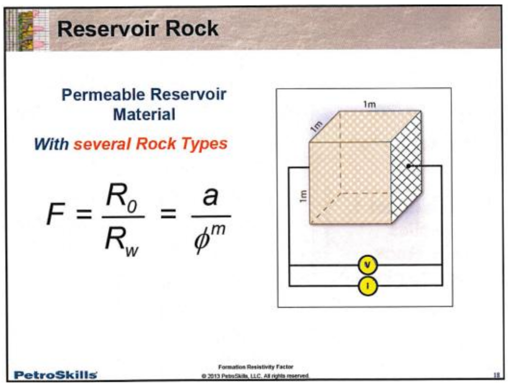
Day 4 Exercise

1. Formation resistivity factor relates porosity and Res, $F=R_0/Rw=a/phi^m=R_{xo}/R_{mf}$ at what reservoir condition? 100% Sw.

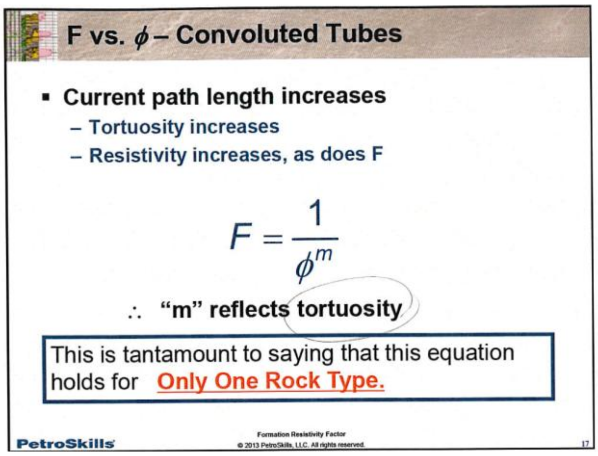




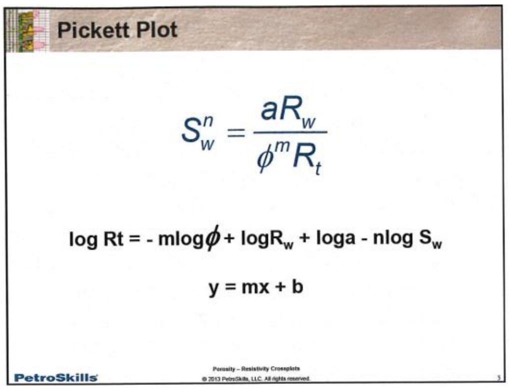


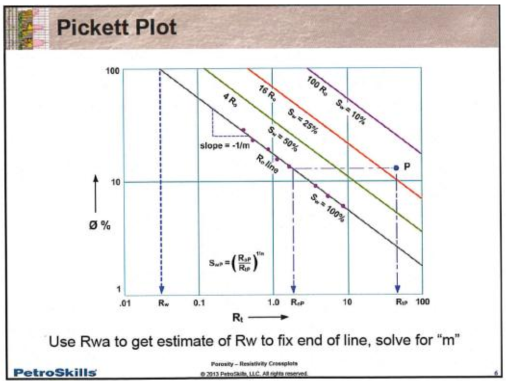


2. Archie Exponent 'm' accounts for tortuosity of reservoir



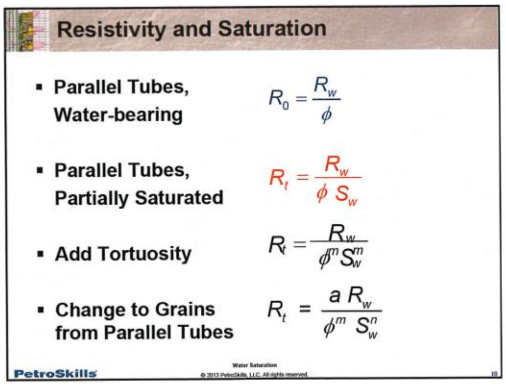
3. A Pickett plot is a plot of Neutron porosity vs Resistivity on Log-Log graph and can be used to determine <u>Rw</u>, <u>m</u>, <u>Sw=(Re/Rw)^(1/n)</u>

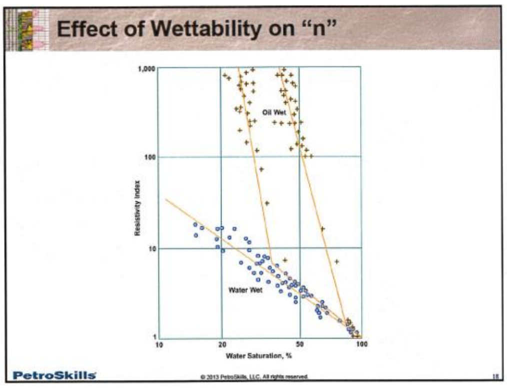




4. Quicklook methods work reasonably well in clean reservoir. Some of these methods are Sw ratio, F_R/F_P, Rwa, Ro overlay

5. How are the Archie exponents "m", "n" similar? Both account for tortuosity of conductive fluid. How are they different? m is at Sw=100%, n is at Sw <100%





6. What are some methods to determine Rw? SP, Pickett /Hingle, Samp, Catelog, Rwa or R_0

7. When determining permeability from porosity's water saturation, what water saturation should be use? Why?

   1. Swirr. 2. Because it's a surrogate for gain surface are/grain size.

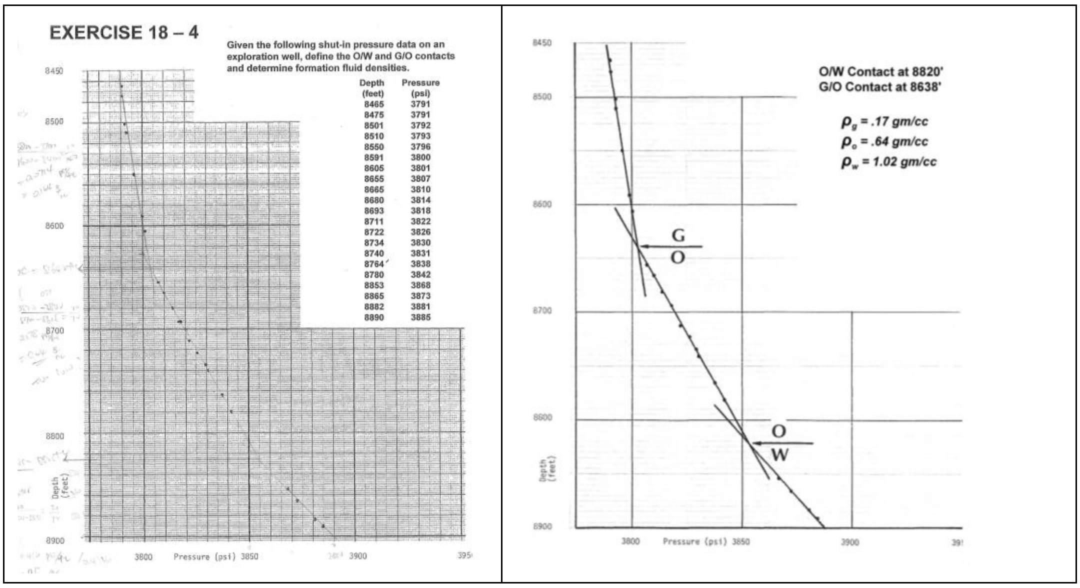
8. In a porr connected pore system high values for 'm' should be expected and in a

well-connected pore system low values should be expected.

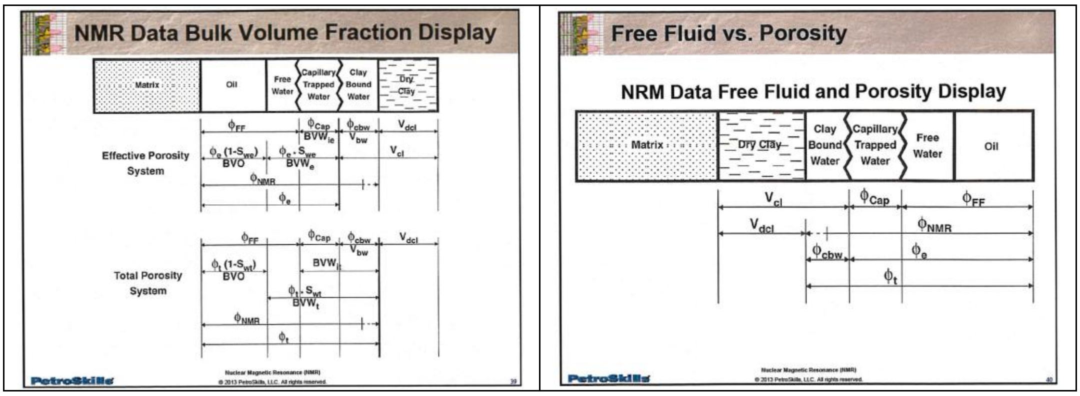
12月11日

Final exam

1. Pressure gradient



2. NMR



3. Final Exam

12月12~13日：回程(休士頓－台北)

參、心得與建議

1. PetroSkills 為國際知名的石油工程訓練機構。本次訓練課程共有 16 位人員參加，學員背景包含地質、鑽井工程、油層工程許多不同領域的人員，其中超過一半目前均任職由知名石油公司如 ExxonMobil (4 位)，Chevron (2 位)，Repsol (2 位)，Shell (1 位)及 BG (1 位)。因此除了學習相關技能外，亦藉此機會了解國外油公司如何培養專業人才，未來可持續以 e-mail 與他們保持聯繫，相信對往後之工作也會有所幫助。
2. Tight sand
3. Fracture
4. Mineralogy
5. Sw Rw
6. 在低油價時代如何將低開採成本與維持穩定開採是關鍵議題，Artificial Lift System 的最佳化設計是一個方向，
7. 此次藉由參與國際會議的機會進行資料收集，同時亦利用機會與有關之專家研討及交換研究心得，吸取他們之技術經驗、增加資訊及知識的雙向交流，使深度與廣度都得以提昇、拓展人脈關係及研究資源。
8. 期許未來能將本趟出國所學習之技術應用於相關研究，拓展本公司的自有能源。

肆、致謝

感謝所內長官給予這次機會，與所有在會期間提供之相關的建議。