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References

Fundamental of well-log interpretation

Vol-1: the acquisition of logging data celsevier

O. serra

well logging for earth scientists

Assessment:

Attendance	١٠٪
Quiz and assignment	٢٥٪
project	١٨٪
final exam	٤٠٪

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Part 1: An overview of well logging

- oil and gas reservoirs lies deep beneath the earth's surface. geologists and engineers cannot examine the rock formations in situ
- surface seismic
- core measurment
- drilling cuttings
- well logs (remote sensing) سنجش از دور
- well tests

مستقیم ترین گروه اطلاعاتی well log می باشد

ثبت پیوسته یک خصوصیات از لایه های زیر زمین در محل چاه حفر شده را فراهم گیری

می نماید معمولاً یک خصوصیت فیزیکی می باشد

اطلاعات چاه بر اساس عمق اندازه گیری می شود

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منظور از پیوسته این است که مثلاً از هر 50 m ، اطلاعات را می گیریم و آن ها را

؟ هم متصل می کنیم

نمونه های مورد نیاز از زیر زمین :

Cores: they donot provide continuous information

Cuttings: are in cotact with drilling mud and some of

its properties is changed

well logs: can provide continuous information about

subsurface

Coring یک عملیات گران قیمت است و در interval های خیلی نمی توان بدست

آورد

گل حفاری خورده های ناشی از حفاری را بالا می آورد مشکلات آن یکی کوچک

بودن آن دوم در ارتباط بودن این خرده ها با گل حفاری می باشد و خصوصیات

خودرا از دست می دهد. خورده ها وقتی در عمق زیاد هستند مدت زمانی طول

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می کشد تا به سطح زمین برسد و ما دقیقاً نمی دانیم که این خرده ها مربوط به

چه intervali می باشد و مشکل چهارم mud loss می باشد که در اینصورت

خرده ها به سطح نمی آیند

اطلاعات mud logging اطلاعاتی را به حفار می دهد تا حفاری ایمنی داشته باشد

و در شبیه سازی مخزن از اطلاعات mud logging نمی توان استفاده کرد

انواع نمودارگیری

1- wireline logging (WL)

1A- wireline open-hole logging نشده casing

1B- wireline cased-hole logging شده casing

2- LWD (Logging while drilling)

wire line log، با استفاده از کابل تجهیزات به داخل چاه فرستاده شده و اطلاعات

بوسیله ی همان کابل به سطح منتقل می شود

در open-hole چون casing ندارد داخل چاه گل داریم

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در نمودارگیری دکل ثابت است

نمودارهایی مثل اندازه گیری قطر ومقاومت صوتی در openhole

نمودارهایی مثل CBL برای چسبندگی casing به دیوار و VDL برای ضخامت

سیمان استفاده می شود در cased_hole

به ابزار نمودارگیری گفته می شود Logging sonde:

در عملیات دریایی کابین نمودارگیری بر روی دکل ثابت است ودر خشکی در پشت

کامیون قرار دارد و متحرک است

کابل دارای دو قسمت است بیرونی ودرونی . قسمت بیرونی استحکام می بخشد

و قسمت درونی اطلاعات را به سطح منتقل می کند

برای قرار گرفتن sonde در کنار دیواره یا مرکز از بازوها یا فنرهای مخصوص استفاده
bow springs arms

می شود

چند ابزار نمودارگیری را به هم متصل می کنند ویک رشته اندازه گیری درست می کنند

ودر هر دور عملیات نمودارهای مختلفی را بدست می آورند

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open-hole wire line logging

حفاری متوقف می‌شود و ابزار به سنگ‌ها فرستاده می‌شوند

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ثبت یک مشخصه فیزیکی از لایه های زیرزمین برحسب زمان را نمودارگیری می گویند

Logging while drilling (LWD)

The logging tools are mounted on the drill string and the measurements are made in real_time, whilst the well is being drilled

LWD is verg efficient in horizental drilling

MWD: Measurment while drilling

در این log ها Rate نشاورد چرخش متهٔ وزن روی متهٔ و... را اندازه گیری می کند تا به حفار در حفاری کمک کند. اما LWD علاوه بر این اطلاعات اطلاعات Wireline logging را هم انجام می دهد و ابزار MWD در کنار LWD استفاده می شود

difference of LWD and wireline:

LWD data are recorded in_time driven mode

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this result in uneven sampling rate of data when put on a depth mode

در LWD log برحسب سرعت حفاری و زمان می باشد و به همین دلیل sampling برحسب عمق یکنواخت نیست interval

The LWD tools may transmit data to surface in real time basis or store it in a down hole memory from which it may be downloaded when the assembly brought back to the surface.

□ Their use may be justified when:

- real time information is required for operational reason e.g. steering a well
- aquiring data prior to the hole washing out or invasion occurring

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-safeguarding information if there is a risk of losing the hole

- the trajectory where wire line acquisition is difficult

Whashing out ← حل شدن بیش از حد گل حفاری - برای مثال در سازند های رسی مقداری از بین در گل حفاری حل می شود و قطر چاه افزایش می یابد

mud invasion ← مثلاً وقتی که سازند حفاری شده تراوایی و تخلخل بالا داشته باشد گل وارد سازند می شود و قطر چاه کاهش می یابد

؟ حالا در دو مورد بالا و جاهایی که گرفتیم را باید قطر چاه را تصحیح کنیم

- در صورت از دست دادن چاه ما اطلاعات لایه های زیر زمین را می توانیم ثبت کنیم

- برداشت نمودارهای کابلی مشکل باشد مثل زاویه ی انحراف بیشتر چاه

The role of well logging in petroleum industry

- ☐ formation evaluation
- ☐ completion evaluation

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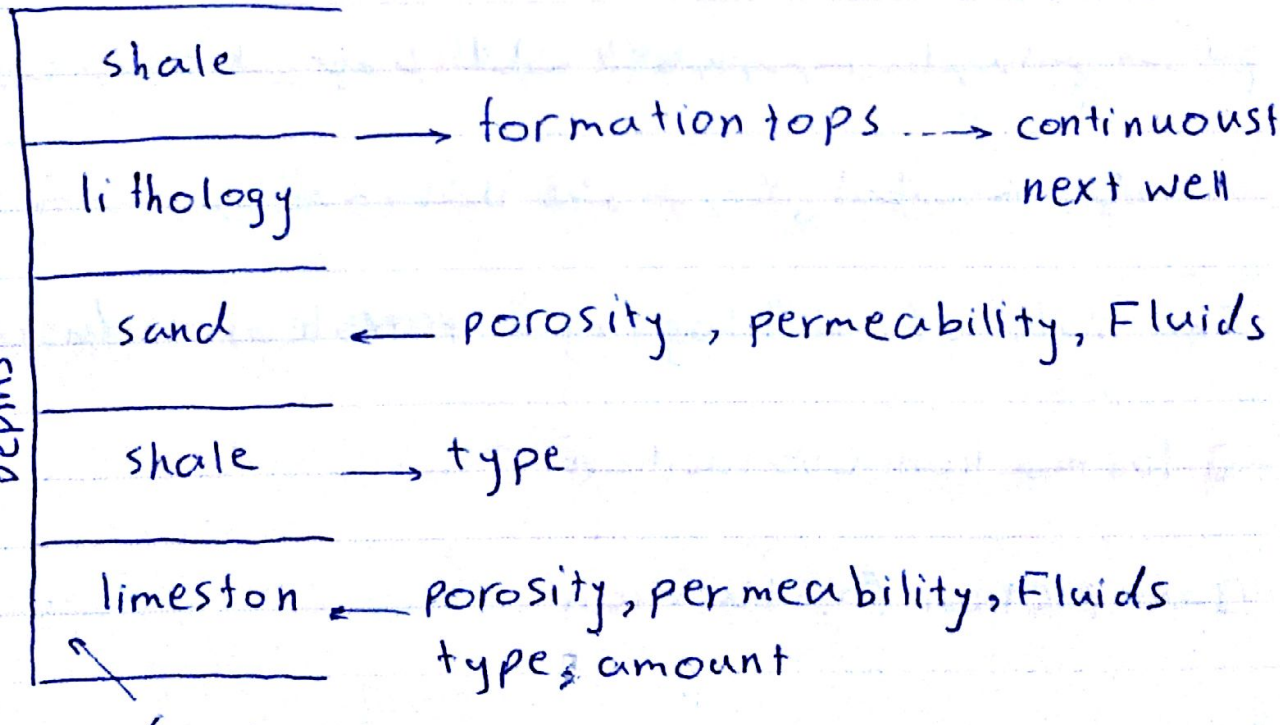
Formation evaluation: (the scope of course)

- Are there any hydrocarbon, oil or gas?
- where are they?
- How much are they in formation?
- How productable are they?

completion evaluation

cement quality, pipe and tubing corrosion, pressure

production logging service



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- می‌خواهیم بدانیم آیا مخزن با کیفیت ارتباط دارند و گستردگی مخزن

- چقدر از نفتی که زیر زمین است قابل بازیابی است و چگونه تولید کنیم و آیا به EOR نیاز است یا نه

نمودارهای مختلف را وقتی کنار هم قرار می‌دهیم برحسب عمق،

می‌توان با گاما Ray Sand, Shale تشخیص داد.

با Resistivity log می‌توان hydrocarbon , brine را تشخیص دهیم

با Neutron porosity, Bulk density گازدهی و مایع را بدست آوریم

Mud logging: (خارج از مباحث این درس)

گلی که به سطح می‌آید تکه‌هایی با خود می‌آورد که نشانه‌هایی از سیالات زیرزمین نشان می‌دهد

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Fundamentals of quatitative

هدف از این بخش:

خواص سیال مربوط به well log مثل porosity, saturation, resistivity و ارتباط آن‌ها با یکدیگر

chapter 1. o. serra

سوالاتی که باید پاسخ دهیم

آیا هیدروکربن داریم؟ آیا می‌توانیم در سازند هیدروکربن داشتیم؟

نفت است یا گاز؟

مقدار آن چقدر است؟

آیا قابل بازیابی می‌باشد؟

Physical properties:

porosity:

ϕ: pore space fractional volume

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$1-\phi$: matrix material fractional volume

There several kinds of porosity

Total porosity: all void spaces between solid components

$$\phi_t = \frac{\text{pore volume}}{\text{Total (bulk) volume of rock samples}} = \frac{V_b - V_s}{V_b} = \frac{V_p}{V_b}$$

connected porosity: is made up only of those spaces which are in communication

$$\phi_{correct} = \frac{\text{Interconnected pore volume}}{\text{Total (bulk) volume of rock sample}} = \frac{V_{p\,connected}}{V_b}$$

$\phi_{connected} << \phi_t$

Potential porosity: is that part of the interconnected porosity in which the diameter of the connecting channel is larger enough to permit fluid to flow

oil can flow through channel with diameter > 20 μm

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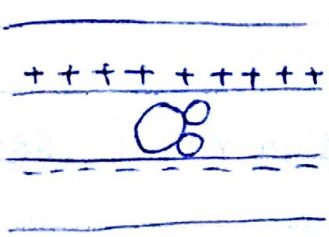
Gas can flow through channels with diameter > 1 μm

potential porosity ← connected porosity ...

Effective porosity: is the porosity accessible to free fluids ...

Effective porosity excludes

- non-connected porosity
- the volume occupied by clay-bound water or clay-hydration water surrounding the clay particles



در تخلخل موثر همان فضاهای متصل می باشد که سیال می تواند داخل آن حرکت کند

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primary porosity: is formed when the sediments are deposited

secondary porosity: is formed after the sediment was deposited

$\phi_t = \phi_i + \phi_r$

Two major types of primary porosity:

- Intergranular / Inter particle porosity:
  occurs between grains of sediments
  is more typical of sand stones
- intergranular / Intra particle porosity:
  occurs within grains themselves
  is typical of newly deposited skeletal of lime sand
  (It is seldom preserved because of porosity loss by cementation)

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primary porosity depends on the shape, size, arrangement of the solids

secondary porosity: had been subdivided into three classes based on the mechanism of formation

- solution porosity
- fractures, fissures, cracks
- dolomitization

logs { Density, Neutron } ϕ_t

logs { Sonic } ϕ_i

Saturation:

S_w: fractional of porosity that contains water

$$S_w = \frac{V_w}{V_P}$$

S_o: $S_o = \frac{V_o}{V_P}$

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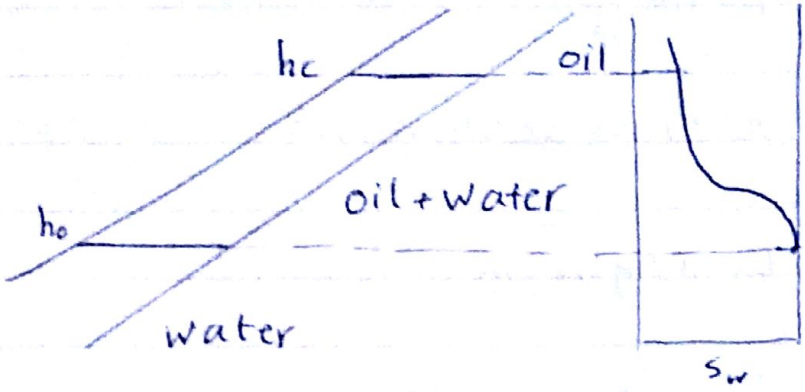
S_g : $S_g = \frac{V_g}{V_p}$

$S_w + S_g + S_o = 1$

$S_w + S_h = 1$



اگر Shale با شدت تیز بین سیالات sharp نیست و کاهش تخلخل تا حدی transition بیشتر می‌شود

و log resistivity مشخص می‌شود

S_{wirr} : irreducible water saturation آب غیرقابل دسترس بودن

S_{or} : residual oil saturation EOR نفت غیرقابل دسترس بودن

Resistivity:

- The electrical resistivity of a material is a measure of its opposition to the passage of electrical current
- It expressed in ohm-meter^2/meter, usually written as ohm-m.

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

A: cross section, m^2

L: length, m

V: Voltage (volts)

I: current (Amperes)

r: Resistance, Ω

R: Resistivity, $\Omega \cdot m$

$V = rI$, $k = \frac{A}{L}$

$r = R \cdot \frac{L}{A} \Rightarrow R = r \cdot \frac{A}{L} \Rightarrow R = \frac{V}{I} \cdot \frac{A}{L} = \frac{V}{I} \cdot k$

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Resistivity - property of a material - copper

Resistance - property of an object - cable

سازند های متراکم تر مقاومت الکتریکی بالایی دارند و نمک ها بیشتر از این ها

material resistivity می باشد چون تخلخل آنها کم است

silver $1,59 \times 10^{-8}$ $\Omega.m$

quartz 2×10^{14}

petroleum 2×10^{16}

common formation resistivities

soft formations - shaly sands $0,2 - 0,5$ $\Omega.m$

Hard formation - carbonates $100 - 1000$

Evaporates - salt and anhydrite > 1000

Conductivity ($\neq$ Resistivity)

هدایت الکتریکی که عکس مقاومت می باشد

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Material's ability to conduct electricity

It is expressed in the units of mmho/m

(milli mhos/m) or $\frac{mS}{m}$ (milli siemens/m)

$C = \frac{1000}{R}$ (inverse of Resistivity

برای اندازه‌گیری Resistivity , conductivity از یک سری ابزار الکتریکی استفاده می‌شود

two kinds of conductivity

a) electronic conductivity is a property of solids such as graphite, metals (copper, silver, etc) metal sulphides (pyrite, galena)

The kind of conductivity is due to the movement of electrons

b) Electrolytic conductivity is a property of, for

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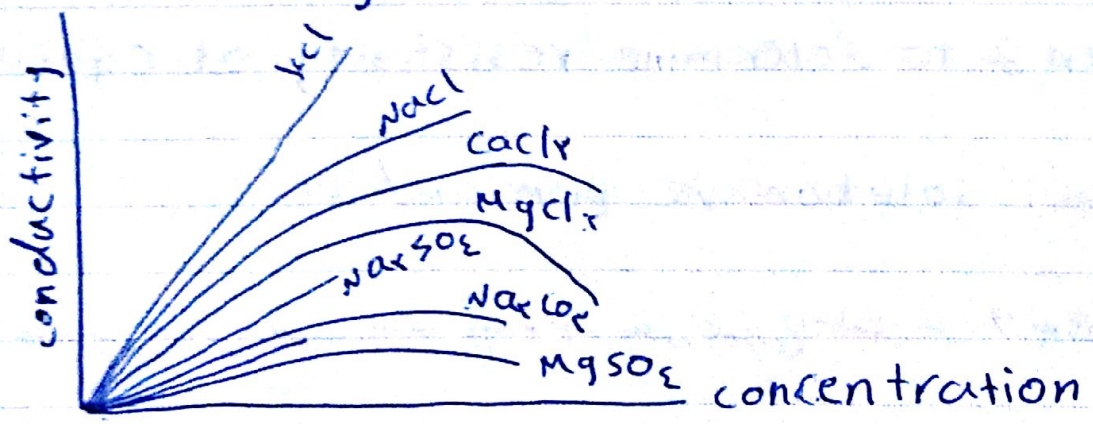
instance, water containing dissolved salts This kind is due to the movement of anions and cations

Relation between resistivity and salinity

resistivity decreases as salinity increase up to a maximum beyond which, undissolved salt impede the passage of current-carrying ions

The salinity is a measure of the concentration of dissolved salts. It expressed in parts per million (ppm or $\frac{\mu g}{g}$ of solution)



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Relation between resistivity and temperature

resistivity decreases as the temprature increases

$$R_{W T_2} = R_{W T_1} \left[\frac{T_1 + 6.77}{T_2 + 6.77} \right] \text{ in } ^\circ F$$

$$R_{W T_2} = R_{W T_1} \left[\frac{T_1 + 21.4}{T_2 + 21.4} \right] \text{ in } ^\circ C$$

Determination of resistivity of solutions

A- direct measurment

B- using empirical charts (with known ppm)

Gen 9 to determine resistivity of Nacl solution

vs. ppm and T

Gen 8 to determine resistivity of equivalent

Nacl solution vs. ppm and T

Gen 9: قاعده دما و محور عمودی سمت راست ppm و محور عمودی سمت

چپ مقاومت می باشد

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Gen 8:

۴۶۰ ppm Ca ۱۴۰۰ ppm SO_4 ۱۹۰۰۰ ppm NaCl

what is equivalent NaCl concentration

total solid concentration

۴۶۰ + ۱۰۰۰ + ۱۹۰۰۰ = ۲۰۱۸۰ ppm

Entering the Chart with total solid concentration

۰/۸۱ as the Ca multiplier
۰/۴۵ as the SO_4 multiplier
} ضرایب (محور عمودی چپ)

۴۶۰ × ۰/۸۱ + ۱۴۰۰ × ۰/۴۵ + ۱۹۰۰۰ × ۱ ≃ ۲۰۰۰۰ PPm

محور افقی total solid concentration و محور عمودی هم یک ضریب می باشد

بعد با استفاده از ppm ۲۰۰۰۰ salinity می توانیم با استفاده از نمودار Gen9 در هر دما resistivity را بدست آوریم

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Resistivity and conductivity

NOTE:

Dry rocks have extremely high resistivity (with exeptional in previouse slides)

The conductive properties of sedimentary rocks are of electrolytic origin - the presence of water (or mixtures of water and hydro carbons) in the pore space

The water phase must of course be continuous in order to contribute to the conductivity (oil-wet rocks do not have these continuous water phase)

The resistivity of a rock depends on:

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- The resistivity of the water in the pores (R_w)
- The quantity of water present (ϕ and S_w)
- The lithology, i.e the nature and percentage of clays present and traces of conductive material
- The texture of rock, i.e. distribution of pores clays and conductive material
- Temperature

Relationship between porosity and resistivity:

In a clean formation saturated with water (aquifer), the formation Resistivity R_o is proportional to that of brine R_w:

$$R_o \propto R_w$$

$$R_o = F_R R_w \Rightarrow F_R = \frac{R_o}{R_w}$$

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F_R = formation resistivity factor

R_o = resistivity of formation saturated 100% with water, Ωm (اشباع ۱۰۰٪ آب R_{oil} ؛)

R_w = resistivity of formation water. $\Omega . m$

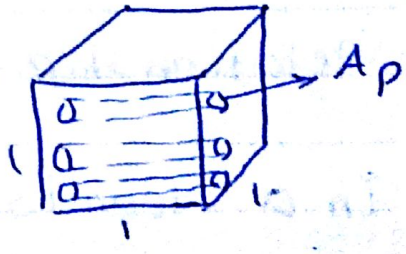
In an ideal condition

relation between F_R and porosity of rock

$(S_w = 1)$

$$r = R\frac{L}{A} = R\frac{1}{1\times 1} = R$$

$$R_o = R_w \frac{L}{S_p}$$



$$\phi = \frac{V_p}{V_b} = \frac{1\times S_p}{1\times 1\times 1} = S_p$$

$S_p = \sum A_p$ pore

$$F_R = \frac{R_o}{R_w}$$

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

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In Reality

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

a = coefficient depending on lithology ۰٫۶ to ۲٫۵

m = cementation or tortuosity factor ۱ to ۳

در واقعیت شکل حفرات منظم و افقی نیست و شکل حفرات عبور جریان را تحت تأثیر قرار خواهد داد

- sand stones and detrital quartz formation (with intergranular porosity)

Humble formula

$$F_R = \frac{۰/۶۲}{\phi^{۲/۱۵}}$$

- well consolidation formation

$$F_R = \frac{۱}{\phi}$$

- non-fissured carbonates of low porosity

shell formula: $F_R = \frac{۱}{\phi^m}$ that $m = ۰/۱۸۶ + \frac{۰/۰۱۹}{\phi}$

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Relation between saturation and resistivity

Archie's formula

R_t is true resistivity of Rock $0 < S_w < 1$

power Law model

$$I_R = \frac{R_t}{R_0} = S_w^{-n}$$

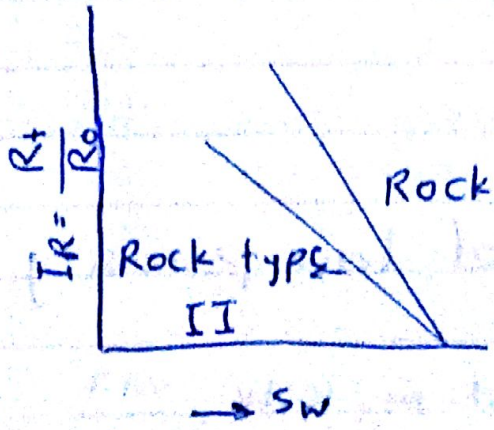
I_R: resistivity index

$I_R = 1$ when $S_w = 1$

$I_R > 1$ when hydro carbons present

- Each curve for a specific core sample
- No conductive materials (clay) present

شیب این خط همان n می باشد



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$$S_w^n = \frac{R_o}{R_t}$$

R_o: Resistivity of shale free rock saturated with formation water ($S_w = 1$), $\Omega.m$

R_t: True resistivity of formation containing water at water saturation of S_w and hydrocarbon saturation of $(1 - S_w)$, $\Omega.m$

R_w: Formation water resistivity, $\Omega.m$

n: saturation exponent ($n = 1.2$ to 2.2)

we can Replace R_o by $F_R . R_w$ the:

$$S_w^n = \frac{R_o}{R_t} = \frac{F_R R_w}{R_t}$$

$$S_w = n\sqrt{\frac{a R_w}{\phi^m R_t}}$$ m: cementation exponent

$m = 2$ $n = 2$ $a = 1$ اگر سوال یا ما نداد مقادیر را به صورت مقابل در نظر می‌گیریم

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What are silt, clay and shale?

Clay: extremly fine grained natural sediment or soft rock consistant of smaller than $\frac{1}{256}$ mm. It contains hydrous silicates of Al, Mg, Fe and minor quantities of finely divided quartz, feldspars carbonates, iron oxides and etc

silt: rock fragment or detrital particles having a diameter in the range of $\frac{1}{16}$ mm to $\frac{1}{256}$ mm. It has commonly a high content of clay minerals associated with quartz, feldspar and mica

Shale: is a fine-grained, indurated sedimentary rock formed by the consolidation of clay or silt It has stratified structure (laminate ... mm thick)

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cation exchange capacity (CEC)

clays are very thin sheet like particles. but have a large surface area depending on the clay mineral type. there is a deficiency of positive electrical charge within the sheet. this creates a strong negative electrical field perpendicular to the surface of the clay sheet which attracts positive ions and repels negative inions present in the water this property is called cation exchange capacity (CES)

structure of clays

Important note

when dealing with formation contains clay therefore we can no longer consider the solid matrix to be non-

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conductive. This has to be taken into account in calculations based on resistivity measurments (formation factor, porosity, saturation, ...)

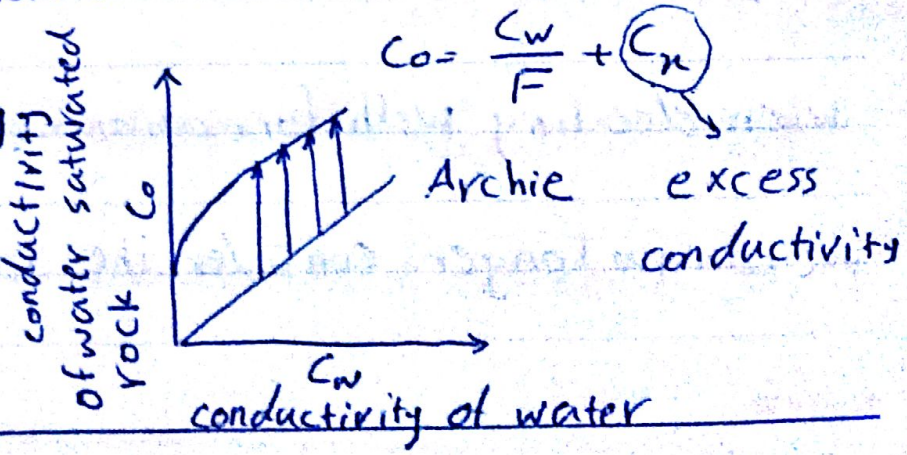
The presence of conductive shales in a formation influences the resistivity measurment

consider two formation: one is clean, one is shaly same ϕ and same saturation

They will not exhibit the same resistivities

The resistivity of the shaly formation will depend on the shale-type, the percentage present, and its manner of distribution in the rock

Excess conductivity



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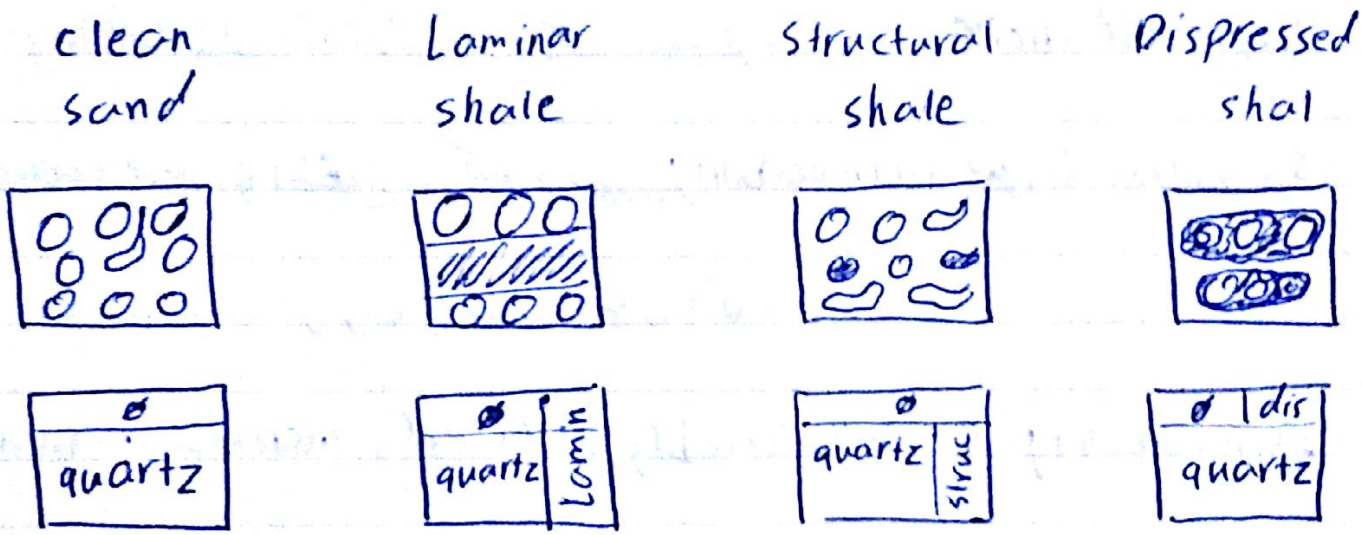
The effect of shale distribution

- Laminar shale
- Dispresed shale
- structural shale



each mode has a different effect on the resistivity , sp and acoustic velocity, and influences reservoir permeability and saturation in a different way

Laminar shale ، ؟ صورت لایه ای شیلی می باشد

shale layers don't alter the effective porosity,

saturation or permeability of each intermediate reservoir layer

vertical permeability, را تغییر می‌دهد و افقی

$$S_w = \left[\left(\frac{1}{R_t} - \frac{V_{sh}}{R_{sh}}\right)\frac{F_{sd} R_w}{1 - V_{sh}}\right]^{0.5}, \quad V_{sh} = \frac{\Sigma h_n}{L}$$

dispresed shale: clay ها اطراف سنگ را می‌گیرند و یک قسمتی از فضای

pore space را اشغال می‌کنند و بر روی permeability خیلی تاثیر دارد و S_w

افزایش یافته و توانایی حرکت سیال را کاهش می‌دهد

permeability is considerably reduced - increase in water saturation and a reduction in fluid moriability

$$S_w = \frac{\left[\frac{aR_w}{\phi_z^2 R_t} + \left(\frac{q(R_{sh}-R_w)}{2R_{sh}}\right)^2 - \frac{q(R_{sh}+R_w)}{2R_{sh}}\right]^{0.5}}{1-q}$$

ϕ_z = (for fluid and dispresed clay)

q = dispresed clay

S_z = clay-water mixture

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$q = \frac{\phi_s - \phi_d}{\phi_s}$ که ϕ_d حاصل از density log و

ϕ_s حاصل از sonic log

structural shale: like dispressed clays

they are somewhat weaker for the same shale

fraction

Subject:
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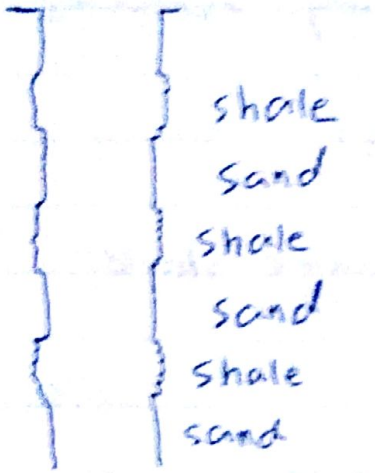
borehole environment



borehole washout in the shale zones
Mud cake in the porous and permeable zone

در برابر سازند تراوا و متخلخل گل حفاری داخل سازند نفوذ می کند و تشکیل mud cake می دهد.

mud filtering ← مواد محلول ، مایع یا آبی گل حفاری که در سازند نفوذ می کند

در برخی ترکیبات شیلی ، shale ها باد کرده و چاه را تنگ تر می کند که به آن sloughing shale می گویند و در برخی هم shale ها شسته شده و حفره چاله افزایش می یابد که به آن brittle shale می گویند

Process by which mud filtrate is forced into permeable formations and the solid particles of

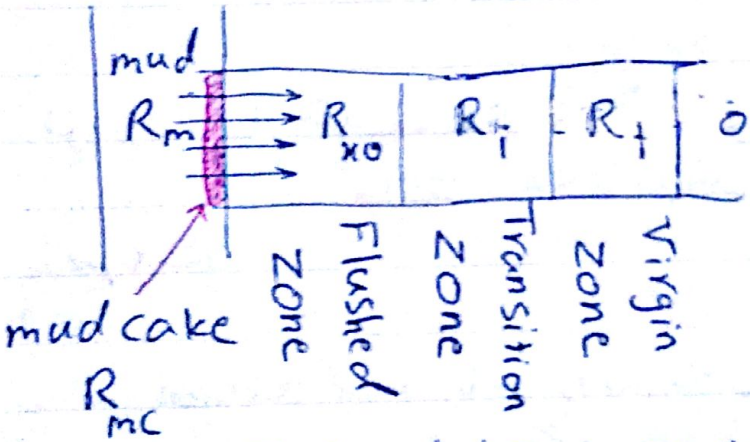
Subject:
Date

the mud are deposited

The mud invasion is normally rapidly stopped by the build up of a mud cake of clay particles in mud.

R_m: resistivity in mud

wellbore



Virgin zone: به این ناحیه گل نرسیده و دست نخورده است

flush zone: mud filterate کاملاً جایگزین سیال مخزن شده است و پس مانده های نفت و گاز مانده است

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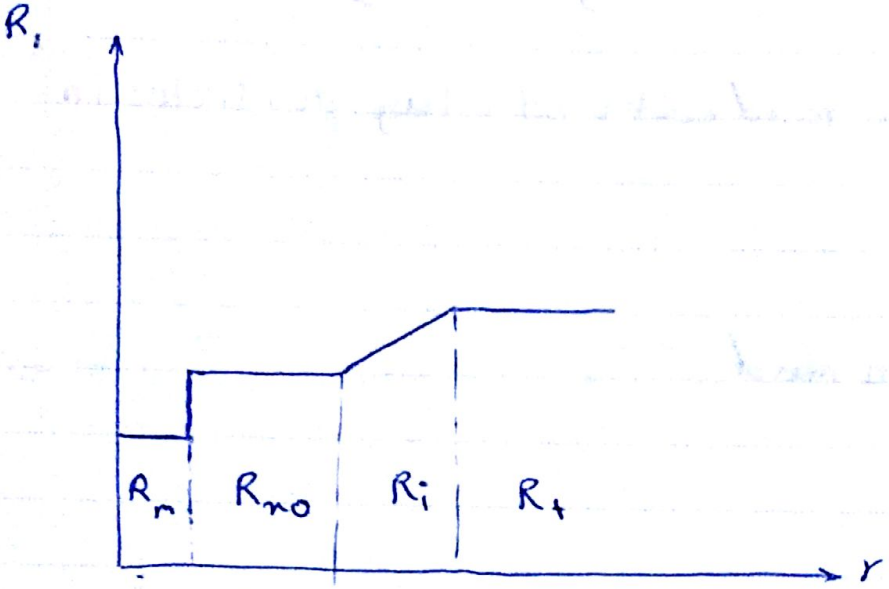
transition zone : اشباع گل و نفت و گاز متغیر است

به علت وجود پسماند نفت و گاز در flush مقاومتش بیشتر از کیک گل است

$R_{xo} > R_{mc}$



این برای تمام شرایط مخزن یکسان نیست و می تواند با توجه به ویژگی مخزن متغیر باشد

میزان mud invasion تابع دانسیته و تخلخل mud filterate و تراوایی گل

می باشد که mud filterate خود تابع آب موجود در گل می باشد

مقاومت mud cake در حدود $\frac{1}{3}$ برابر مقاومت گل داخل چاه می باشد

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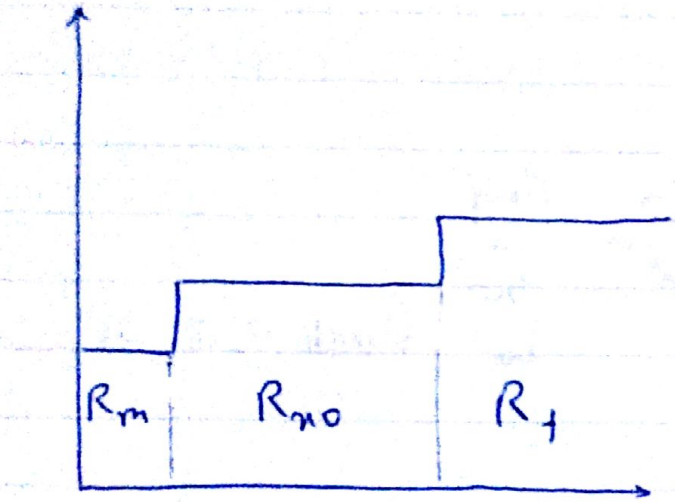
در بعضی مواقع درک درستی از transition zone نداریم در اینصورت یا در قسمت تقسیم می‌کنیم و یک قسمت به flush و یک قسمت به Virgin اضافه می‌شود



هرچه porosity بیشتر باشد معمولا mud filtrate کمتر است.

نرخ تشکیل mud cacke با نرخ mud filterate یکسان است پس هرچه porosity کمتر نرخ تشکیل mudcake بیشتر و نرخ نفوذ mud filterate بیشتر می‌باشد

ما باید توابع نرخ تشکیل mud cake را کنترل کنیم

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Archie's formula (virgin zone)

$$R_t = \frac{a}{\phi^m} \frac{R_w}{S_w^n}$$

m: cementation factor

flushed zone: $R_{xo} = \frac{a}{\phi^m} \frac{R_{mf}}{S_{xo}^n}$

↳ flush اشباع آب در ناحیه

Fluid mobility

The producible oil index, POI, (also called the movable oil index)

$$POI = \phi (S_{xo} - S_w)$$

if the difference $(S_{xo} - S_w)$ is small, it is likely that the hydrocarbon mobility is poor, and recoverability will be low

The recoverability factor, f, is defined as

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$$f = \frac{(S_{no} - S_w)}{(1 - S_w)}$$

which is simply the recoverable fraction of the intial hydrocarbons in place.

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well log display

Vertical wells:

MSL : Mean sea level

RT : Rotary table

KB : kelly bushing

MD : Measured depth

MD_{ss} : Measured depth sub sea

$MD_{ss} = MD - KB$

Deviated wells:

TVD : True vertical depth

TVD_{ss} : True vertical depth sub sea

MD : Measured depth ($\geq$ TVD)

θ : Angle of inclination

Az : Azimuth

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In vertical wells: TVD = MD

$TVD - TVD_{ss} = KB$

این اطلاعات از log head بدست می‌آید. همچنین باید refrence مشخص باشد و این اطلاعات بر اساس refrence باشد

برای مثال ما از آخر log header مراجعه می‌کنیم و توجه ؟ مقادیر و واحد مختلف را بدست می‌آوریم

نمودارهای Resistivity به صورت لگاریتمی نمایش داده می‌شوند

نمودار Resistivity شامل سه نمودار R_t و R_i و R_{no} می‌باشد

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SP log

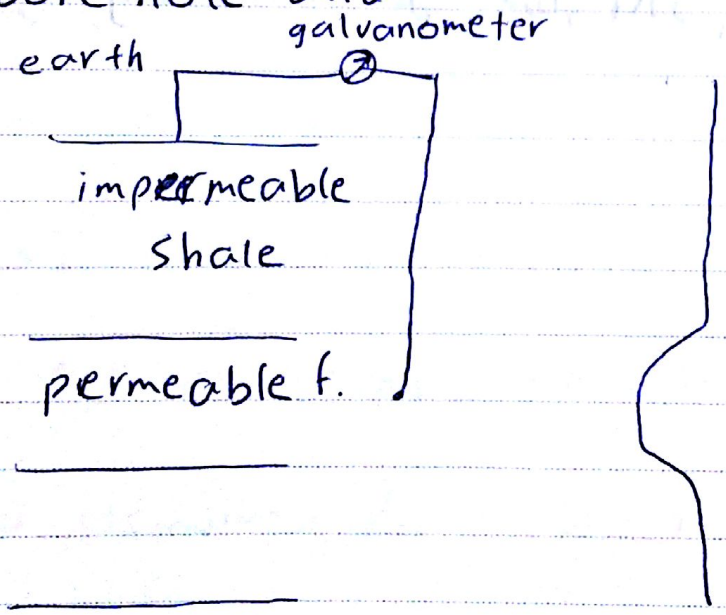
Spontaneous_Potential (self_potential) log

فصل ۴ کتاب O. serra

نمودار تپانسیل خودزا : یک الکترود در داخل چاه و یک الکترود در سطح زمین

یک اختلاف تپانسیل ایجاد می‌کند

An electrical potential difference exists, spotanously, between movable electrode in the bore hole and



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The SP opposite of a formation can be attributed to two processes involving the movement of ions

1- Electrochemical potential_ E_c

1a- Membranee potential_ E_m

1b- Liquid Junction potential_ E_j

E_c- is present when two fluids of different salinities are either in direct contact, or seprated by a semi-permeable membranee (such as shale)

2-Electrokinetic potentials - E_k

E_k- is present while an electrolyte penetrates a porous, non-metallic medium

1a- membrane potential

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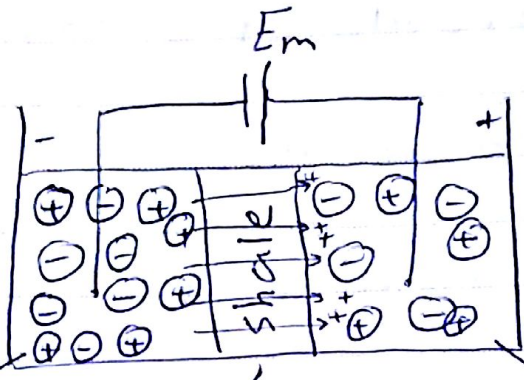
⊕ : Na^+

⊖ : Cl^-



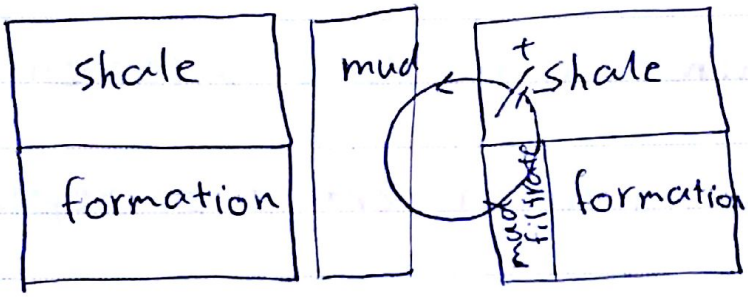
concentrated Nacl

Diluted Nacl

غشا نیمه تراوا

از درجای شوری بیشتر به درجای شوری کمتر

این مثال شبیه گل حفاری و آب سازندی می باشد



$R_{mf} > R_w$

$E_m = k_e \log\left(\frac{a_w}{a_{mf}}\right)$ $k_e = 2{,}3\frac{RT}{F}$

F: faraday constant

R: ideal gas constant

T: absolute temprature

aw: ionic activity of formation water

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a_{mf}: ionic activity of mud filterate

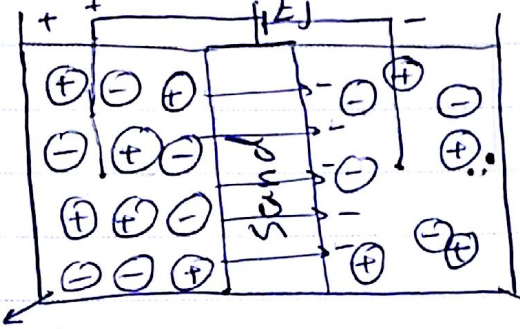
$R_{mf} = 0.75\, R_m$

ما در اینجا mud و آب سازند را مدنظر قرار می دهیم

1b_ liquid junction (or diffusion) potential

⊕ : Na^+

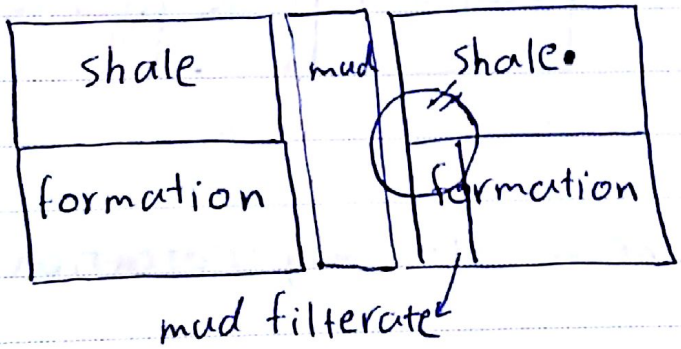
⊖ : Cl^-



concentrated Nacl

Diluted Nacl

$R_{mf} > R_w$



$$E_j = k_\xi \log\left(\frac{a_w}{a_{mf}}\right)$$

$$k_\xi = 2.3\,\xi \frac{v-u}{v+u} RT/F$$

F: faraday constant v = mobility of cl

u: mobility of Na

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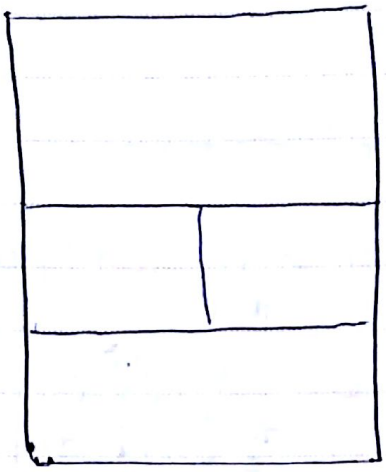
1- electro chemical potential



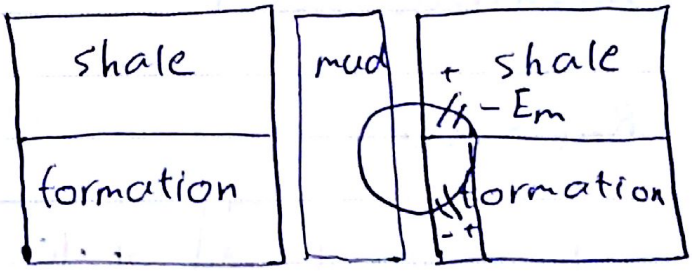
$E_C = E_m + E_j$

$E_C = k \log \left(\frac{aw}{amf} \right)$

$k = k_2 + k_4$

$k = 60 + 0.1333T$

T: °F



2- Electro kine tic (streaming) potential

این اختلاف پتانسیل حاصل اختلاف فشار است

مثل این است که یک الکترولیت را با فشار وارد لوله مویین کنیم

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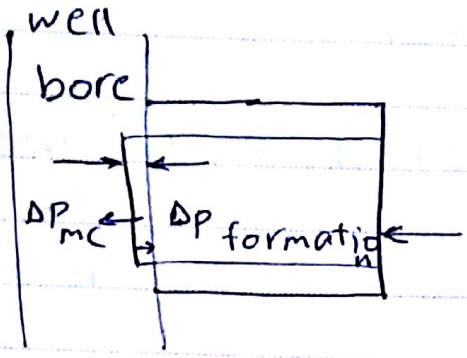

$\Delta P_{mc} \gg \Delta P_{formation}$

$E_{k(mc)} \gg E_{k(forma}$

filterate flow takes place and electro kinetic potential is produced.

a) across the mud_cake in front of the permeable formation

b) across the permeable formation being invaded

c) across the shale beds

when mud filtrate is forced into the formation under the differential pressure between the mud column and the formation

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$E_{k(mc)} = k_1 (\Delta P)^{Y}$ $Y = .1 dV$ to $.9$

This is generated by flow of the mud filtrate through the mud cake. As this does not normally occur this effect is small. It will only become important if there are high differential pressures across the formations

It's presented while an electrolyte penetrates a porous, non-metallic medium

$SSP = E_m + E_j = (R_{xo} + R_{t+} + R_{sh} + R_m) \propto I_{sp}$

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نکات:

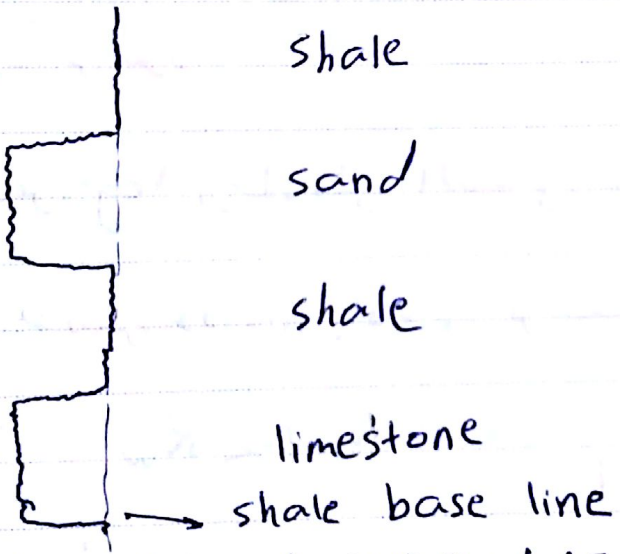
۱. گل باید صورت یک فاز همگن باشد

۲. sp log در چاه های open hole می باشد.

۳. گل باید صورت پایه آبی باشد (مادی حریان)

The sp is measured in millivolts, mV.

در مقابل سازندهای شیلی باید صورت خط راست می باشد و باید عنوان خط مبنای شیل در نظر گرفته می شود



با sp log می توان محل لایه های تراوا و متخلخل را بدست آورد اما مقدار آن ها با این log قابل دسترس نیست

shale base line is positioned by logging engineer

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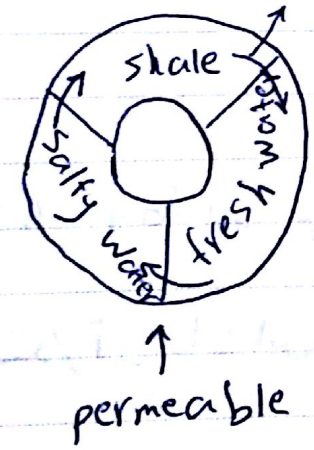
The position of shale base line has no useful meaning for interpretation purpose

SP value is deviation for from shale base line

در اسلاید دوم SP ، -۵،۵ mV sand دارم

اگر انحراف به سمت چپ باشد منفی و به سمت راست shale base line باشد مثبت می‌باشد و در نظر SP=۰mV، shale base line گرفته می‌شود

از این log در چاه‌های آکتشافی برای تشخیص U به تراوا و متخلخل استفاده می‌شود نه در چاه‌های توسعه‌ای.



+SP

$R_{mf} < R_w$

if salinity of mud is more than salinity of formation water, then SP is to right and positive

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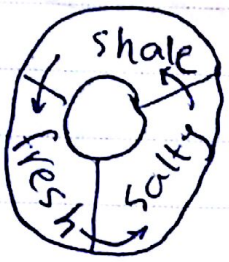

$R_{mf} > R_w$

-SP { If salinity of formation water is more than mud then SP deflection is to the left and is considered negative (-SP)

SP Vs Static SP

SP واقعی کمتر از SSP می‌باشد در SSP فرض می‌کنیم که بالا و پایین لایه‌ی sand عایق می‌گذاریم. ما SP واقعی را ثبت می‌کنیم و اختلاف تبانسیل هر رقم را در نظر می‌گیریم. اگر یک لایه ضخیم sand داشته باشیم SP با SSP نزدیک می‌شود در تفسیر نیازی به تصحیح SP و SSP نمی‌باشد اما در محاسبات باید SP را با SSP تصحیح کنیم

SSP واقعیت لایه‌ی زمین می‌باشد

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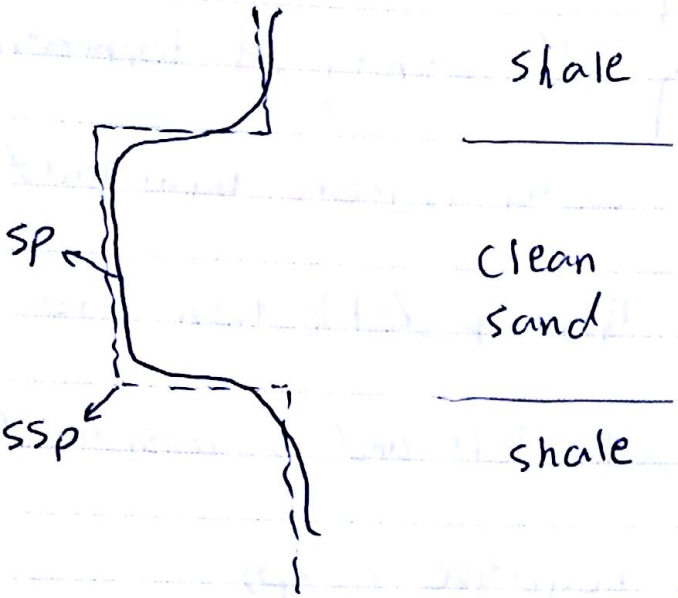
اولین تلفات بر روی sp log هادی بودن گل می باشد.



Effects of different parameters on sp log

۱. قطر چاه

sp با افزایش قطر چاه، کاهش می یابد (میزان تلفات بیشتر می باشد)

و هر چه فاصله ی الکترود از دیواره بیشتر و تلفات بیشتر می باشد

۲. depth of invasion (عمق نفوذ گل در سازند)

sp decrease as depth of invasion increase.

با نفوذ گل در چاه، فاصله بین الکترود و Virgin zone افزایش می یابد

و تلفات افزایش می یابد

Subject:
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ضخامت لایه:

هرچه ضخامت لایه بیشتر sp افزایش یافته و به ssp نزدیک‌تر می‌شود

formation resistivity

The virgin zone

as $\frac{R_t}{R_m}$ increased the sp decreases and the bed boundaries are loss sharply defined the presence of hydro carbons attenuates the sp neighbouring beds.

as $\frac{R_{sh}}{R_m}$ increased, the sp increases (کاهش تلفات موازی هستند)

Invaded zone:

as $\frac{R_{xo}}{R_m}$ increased, the sp decreases.

با تغییر مقاومت ssp هم تغییر می‌کند اما امنت sp در مقایسه با ssp بیشتری باشد

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SP log application

- Differentiate potentially porous and permeable reservoirs rocks from impermeable clays.
- Determine R_w
- Define bed boundaries
- Give an indication of shaliness (maximum deflection is clean; minimum is shale)

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water resistivity R_w

$SSP = -k \log \left(\frac{(R_{mf})_e}{(R_w)_e} \right)$

$SSP = -(60 + 0.133T) \log \left(\frac{(R_{mf})_e}{(R_w)_e} \right)$

T: Temprature, °F

R_w: resistivity of formation water @ formation temprature

R_{mf} = resistivity of mud filtrate @ formation temp

$E_c = k \log \frac{a_w}{a_{mf}}$

$E_c = k \log \frac{(R_{mf})_e}{(R_w)_e}$

salinity < 10 kPPm ($10 \frac{g}{L}$)

$SSP = -E_c$

$E_{SSP} \xrightarrow{SP_1} \frac{R_{mfe}}{R_{we}} \xrightarrow{SP_1} R_{weq} \xrightarrow{SP_2} R_w$

$shale\% = \frac{SP\,log - SP\,sand}{SP\,Shale - SP\,sand}$ دقیق نیست و حدودی می باشد (برای مقدار دقیق از گاما لاگ استفاده می کنیم)

Subject:
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Resistivity log

ثبت مقاومت سازندها و لایه‌های زیر زمین برحسب عمق. قدیمی‌ترین نوع log

سنگی که محاوی آب باشد یا سنگی که هیدروکربن دارد مقاومت‌های آنها باهم

فرق می‌کند برای تعیین saturation نیاز است تا مقاومت سنگ‌ها را ابتدا با

استفاده از این لاگ بدست آوریم.

Resistivity measurment

- conduction Resistivity: Electrode devices
  - low-frequency current sources. in most cases below 1,000 Hz
  - works in conductive muds (water based muds)
- Induction Resistivity: Induction devices (coil based devices)
  - Medium frequency (several 10s of kHz)

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- works in non-conductive muds (oil-based / air based muds)

Conduction Resistivity logging

Electrode devices

Basic of wireline condction resistivity measurment

There are several techniques in use for measur ment of the resistivity.

All variation of common basic system

one (or several) emitter (electrode) sends a signal (electrical current) into the formation.

one (or several) receiver (electrode) measures the response of the formation to this signal at a certain distance from the emitter

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Note 1: logging tools called electrode devices named because the measurment elements are simply metallic electrodes

Note 2: distance between emitter and receiver is called spacing

Note 3: generally, an increase in the spacing results in an improved depth of investigation (and a reading nearer to the true formation resistivity, R_t)

Types of electrode devices

Two main categories of resistivity tools as a function of the spacing value:

1- logng - spacing devices or macro-resistivity devices, or macro-tools which have medium to

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deep reading

Examples: (ES), LL, SFL
the only non-focusing device
ر- Short spacing devices or micro-resistivity devices or micro-tools which have a shallow reading.

Examples: (ML), MLL, PL, MSFL
the only non-focusing devices

از ۱ الکترود ها در بالا و پایین لایه مورد نظر استفاده می کنیم و جریان را بصورت متمرکز در لایه هایی که می خواهیم اندازه گیری را انجام دهیم وارد می کنیم و از همدیگر متمایز جریان جلوگیری می کنیم focused

conduction Resistivity log

Electrode devices

Long-spacing devices or macro resistivity devices
ca) the conventional electrical survey (ES)

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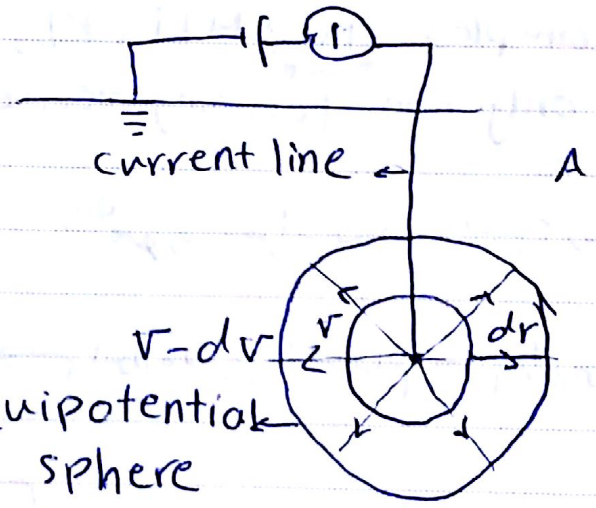
non focused devices

with normal and lateral (or inverse) electrode arrays

The potential difference between any two radii from single point electrode, A, is defined by ohm's law:

$$V = Ir = IR\frac{L}{A}$$



V = voltage

I = current

R = resistivity

r = resistance

L = Length of conductor over which E is measured

A = cross sectional area of conductor

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For the spherical system

$L = dr$ and $A = 4\pi r^2$

$$-dV = \frac{IR}{4\pi r^2} dr \longrightarrow V = \frac{IR}{4\pi r}$$ محدوده انتگرال از r تا ∞ می‌باشد

Normal device principle

Considering two electrode system,

the potential measured at M due to A is:

$$V_{MA} = \frac{IR}{4\pi (AM)}$$

AM is distance between M and A, which is the spacing of the device. then:

$$R = 4\pi (AM) \frac{V_{MA}}{I}$$

The quantity $4\pi(AM)$ is constant for a particular device

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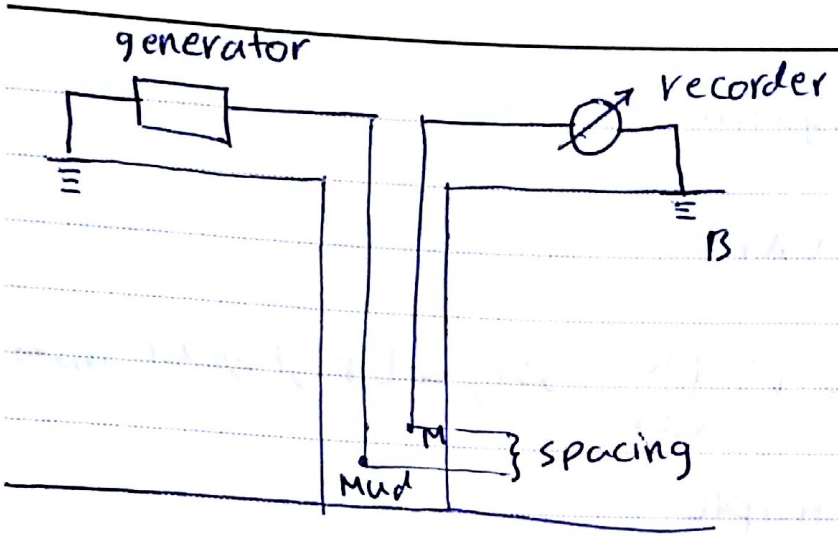


Common spacing for normal devices:

- 16 inches (short normal)
- 64 inches (medium or deep normal)

Measuring point (depth zero):

The depth refrence point is taken at the middle of the spacking. This corresponds to the mid-point of AM

radius of investigation:

2 x AM

Subject:
Date

shapes of curves of normal devices

Shape of curves of normal devices depends on

- bed thickness
- resistivity of formation
- resistivity of mud
- resistivity of adjacent beds (shales)

☐ Thick resistive beds ($h > AM$)

☐ Thin resistive beds ($h < AM$)

Subject:
Date

Lateral (or inverse) device principle

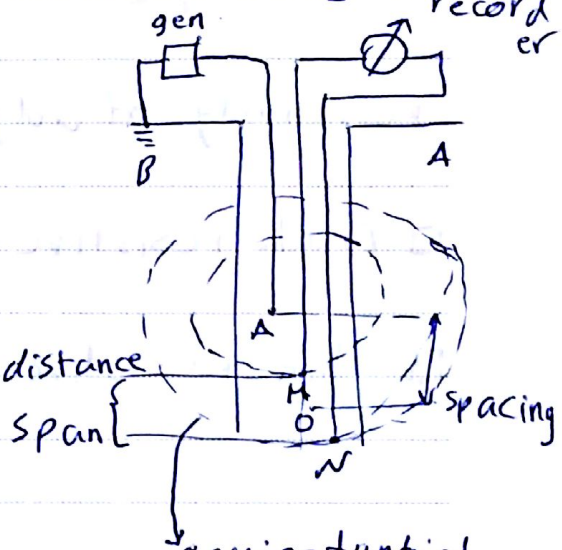
In the lateral configuration, two measuring electrodes, M and N, are placed close together below A

The different ~~dV~~ ΔV between the spherical equipotential surfaces on which M and N lie is derived as below:

$$V_{MA} = \frac{IR}{\epsilon\pi(AM)} \qquad V_{NA} = \frac{IR}{\epsilon\pi(AN)}$$

$$\Delta V_{MN} = V_{MA} - V_{NA} = \frac{IR}{\epsilon\pi}\left(\frac{1}{AM} - \frac{1}{AN}\right)$$

$$R = \frac{\epsilon\pi(AM)(AN)}{AN - AM} \times \frac{\Delta V_{MN}}{I}$$



common spacing for lateral

1A ft 1A in

Radius of investigation

approximately equal to AO $\left(O = \frac{MN}{2}\right)$

Subject :
Date

(a) beds more resistive than adjacent beds and

$h > A_0$

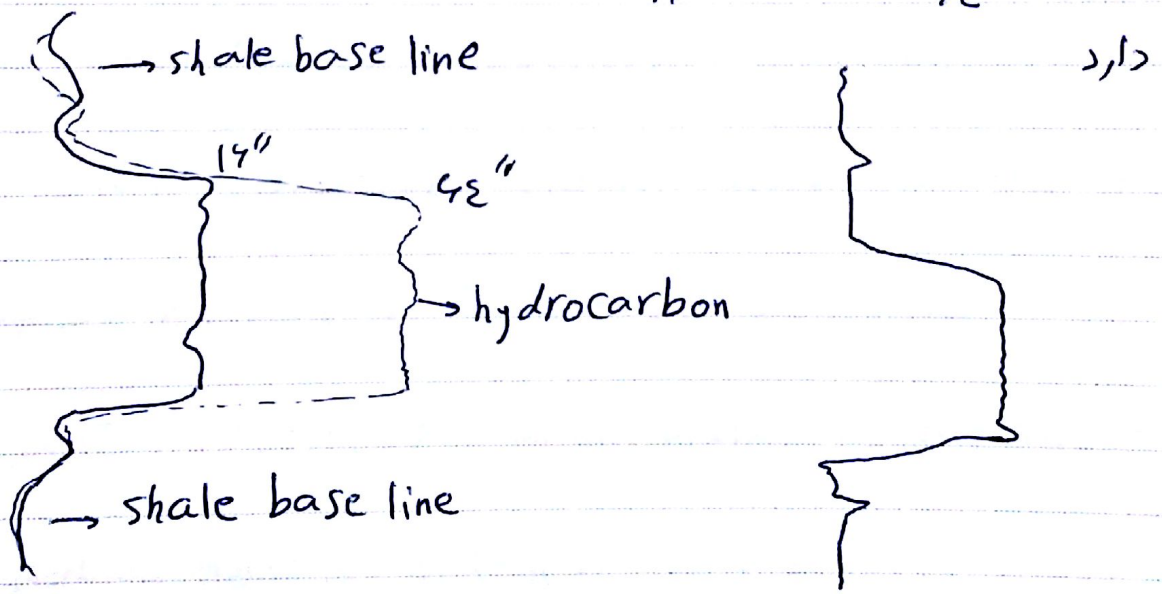
(b) beds more resistive than adjacent beds and

$h < A_0$

اگر نمودار normal و lateral بروی هم بیافتند یعنی invasion نداریم و لایه دارای تخلخل و تراوایی کم می باشد و می تواند مربوط به لایه ی شیلی باشد

shale از نمودار های normal و lateral داریم

وقتی نمودار بردبلند بیشتر از بردپایین باشد یعنی احتمال حضور هیدروکربن وجود دارد



Subject:
Date

Short comings of the long spacing normal and lateral devices:

- In this beds (h < spacing) the R_a is a poor estimate of the R_t
- The bore hole (mud) and invaded zone have a significant effect on R_a
- The available correction charts are rarely 100% effective
- Bed boundaries are difficult to define precisely

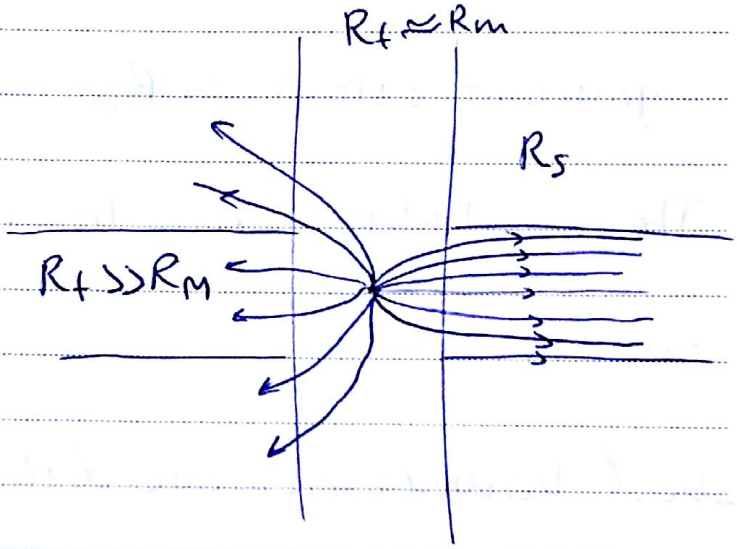
$R_t \gg R_m$: Idealized current paths for the short normal in a very conductive borehole mud

$R_t \gg R_s$: Idealized current paths for the short normal in front of a thin resistive bed

Subject:
Date

Long spacing focusing devices : general principle

On the left the pattern is altered from the expected radial pattern because of the presence of a highly resistive bed. on the right is the desired flow so that the resistivity of the bed of interest is sampled properly.



Latrolog (LL) ابزارها Es از نوع متمرکز و جایگزین

یک الکترود مرکزی فرستنده جریان و حداقل دو الکترود گارد بالا و پایین

یکی از LL ها LL3 می باشد

کار الکترود ایجاد یک اختلاف پتانسیل صفر در بالا و پایین الکترود مرکزی

Subject:
Date

ایجاد می‌کند یا جریان ایجاد نشود در جهت عمودی

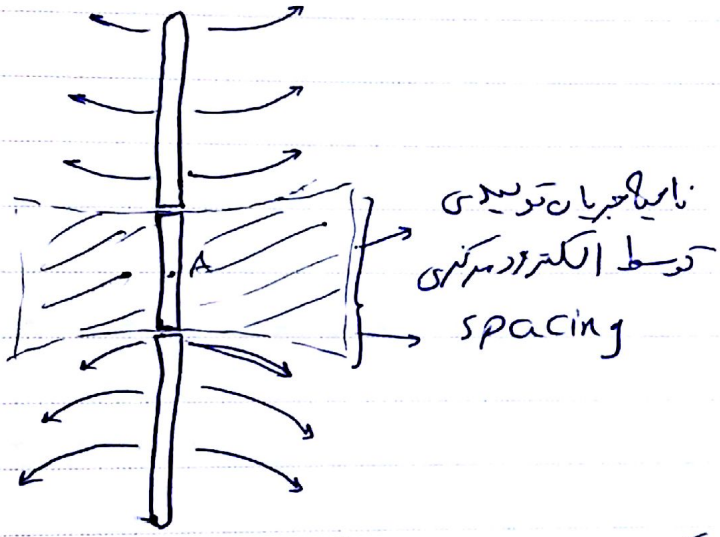
measurment current ⇐ جریان تولیدی توسط الکترود مرکزی

emittiring

buckling current ⇐ " بالا و پایین (گاردی)

Note: LL3 is suited to conductive formation

LLV از ۷ الکترود استفاده می‌کنیم و در نتیجه جریان کمتر می‌شود و عمودتر می‌شود



LL7 دارای یک الکترود مرکزی و ۶ الکترود دارد که در حفاظ الکتریکی ایجاد می‌کند زیرا در مقابل لایه‌های مقاوم‌تر قرار می‌گیرد

Monitoring electrodes drive the buckling current in the guard electrode to maintain a differential voltage of zero

P4PCO

Subject:
Date

This is a shallow reading laterolog, similar to LL8 in design to the LL7, except that the spacings are smaller

(نعاج نفوذ کم)

LL8 درست است نیز macro ماست اما عموماً گوییم که مقاومت RXO را

ما می‌دهد

Subject :
Date

The dual later logs (DLL)

the most common traditional electrode devices use a dual focusing system

This 9 electrode tool makes simultaneous deep and shallow readings (LLd and LLs) or (LLD and LLS)

By rapidly changing the role of various electrodes, a simultaneous measurment of deep and shallow resisfivity is achieved

Vertical Resolution

VR corresponds to the thickness of the current disk

LL3 = ١٢ in LL7 = ٢٢ in LL8 = ١٤ in DLL = ٢٤ in

P4PCO

Subject:
Date

Radius of investigation

LLd measures closest to R_t, followed by the LL3 and LL7. the shallowest readings, close to R_{xo} are obtained with the LLs and LL8

While the LL3 and LL7 are run alone, the LLd and LLs are comprised in the earlier dLL tools

Spherically focused tools

جریان به صورت یک کره ی متمرکز وارد سازند می شود

Another approach to compensating for the effect of the borehole is the concept of spherical focusing

In this technique, which has been adopted for medium and shallow resistivity measurments, bucking currents attempt to establish the spherical

Subject:
Date

equipotential surfaces

Vertical Resolution

equal to distance oo', which is 30 in

Radius of investigation

It depends on spacing

نمودار گاما در سازندهای مخزنی مثل sandstone , limestone یک عدد

پایین را نشان می دهد

درجایی که داده LLD , MSFL برروی هم منطبق شدند نشان

دهنده ی آب می باشد و درجایی که عدد بالایی نشان می دهد نشان دهنده

هیدروکربن می باشد

MSFL مقاومت پایینی را نسبت به Virgin می خواند چون اشباع از نفت و

گاز نیست و نفت و گاز باقی مانده می باشد

از این لاگ می توان هیدروکربن ، محل تماس آب و نفت ، ... می باشد

Subject:
Date

اگر LLd و LLs روی هم بیافتند و MSFL جدا باشد نشان دهنده (عدد کم)
ی این است که mud filtrate نداریم

جدا بودن LLd، LLs، MSFL نشان دهنده‌ی این است که یک ناحیه‌ی transition بزرگ وجود دارد، mud filtrate زیاد است که LLs دارد transition zone می‌باشد

اگر هر سه روی هم بیافتند و عدد بزرگ نشان دهد؟ این معنی می‌باشد که قطر رخنه زیاد می‌باشد LLd، LLs در گل پایه آبی کاربرد دارد آب‌سازندی و گل‌سفاری و شوری آن‌ها تقریباً یکسان می‌باشد.

MSFL همان SFL می‌باشد که spacing آن کوچکتر می‌باشد و shallow را می‌خواند

اگر هر سه روی هم بیافتند و عدد کم بخواند می‌توان گفت که قطر رخنه خیلی کم است و mud filtrate نداریم

Subject:
Date

Induction resistivity logging

coil-base devices

Basics of wireline induction resistivity measurments

Devices based on electrical current sending into formation by electrodes do not workin non conductive muds.

As a magnetic field can travel in any type of fluid, even in air orgas, the idea was to generate a magnetic field by sending through atransmitter coil a high-frequency alternating current.

Induction logging (IL) (two-coil induction device)

توسط یک سیم پیچ فرستنده یک میدان مغناطیسی ایجاد می‌شود و جریان های

سطحی تولید می‌شود و باعث ایجاد میدان مغناطیسی ثانویه می‌شود که توسط

Subject:
Date

ضبط می‌شود receiver coil

در ابزار القایی conductivity اندازه‌گیری می‌شود برخلاف ابزارهای

قبلی که مقاومت اندازه‌گیری می‌شود

Radius of investigation

L: coil spacing (receiver coil and transmitter)

The major part of the electromagnetic field

propagates within a radius $\frac{L}{\Sigma}$ to L

A longe spacing produces a deep investigation

Vertical resolution

A bed thickness of h>L is therefore hardly affected

by the adjacent formations and the vertical

definition is of the same order of magnitude as

spacing

Subject:
Date

نکته: از چندین coil اضافی هم استفاده می‌شود تا اثر گل و چاه های اطراف و لایه های بالا و پایین را به حداقل برسانیم

Dual Induction logging (DIL)

combines:

a deep reading tool (ILD) or (ILd) such as

6FF40

with

a medium reading tool (ILM) or (ILm) such as

6FF28

note: Bed thickness effects become significant in beds thinner than 4inch (6FF40) or 3.5 ...

Why corrections are required for resistivity log?

The resistivity measured by any resistivity tool

Subject:
Date

said apparent Resistivity R_a is a function of several factors.

$R_a = f(R_m, d_h, R_{mc}, h_{mc}, R_{no}, d_i, R_t, h, R_s)$

This is achieved using charts, which are available for

"Bore hole correction",

"bed thickness (and shoulder-bed) correction"

"Invasion correction"

~~To obtain the Resistivity of the no~~

Invasion assumed zero and bed thickness infinite

(bore hole correction: 16-in. Rcor-8)

$\frac{R_{16}}{R_m} \rightarrow d_h \rightarrow \frac{R_{16cor}}{R_m}$

خوانده شده از لاگ — تصحیح شده

برای تصحیح Rcor-8 از هر سه 16'' 8'' 4'' lateral آنرا استفاده می کنیم

Subject:
Date

Bore hole connection : Induction log Rcor 4

stand off : فاصله ابزار از سر چاه

Bed thickness correction : Induction log Rcor 5
۶FF۴۰ (ILD) and ۶FF۲۸

for ۶FF۲۸ : قبل از ورود به نمودار باید ضخامت لایه را در ۱,۴۳ ضرب می کنیم

مقاومت اینجا مقاومت بعد از تصحیح borehole می باشد یعنی اول

تصحیح borehole انجام می شود بعد Bed thickness

Bore hole correction : ۱۶in_normal Rcor.8

Bore hole correction : Rcor_۲b for dual laterolog

Rcor۲b _ Rcor۲c
standoff۱۰ _ ۱,۸

Bed thickness correction : dual laterlog Rcor_۱۰

Bore hole correction : SFL Rcor-1

اثر ضخامت لایه کمتر از normal می باشد

Subject:
Date

Conductive Resistivity logging

Electrode devices

shortspacing devices or micro-resistivity devices

All are mounted on special devices, called pads which are applied against the bore-hole wall by spring. They are designed to read R_{xo}, by virtue of their short spacing and their very shallow depth of investigation

There is avery little borehole fluid effect but the mud cake contributes a small signal

The vertical resolution obtained with these electrode tools is much finer than with the longer spacings.

Subject:
Date

Examples: ML, MLL, PL, MSFL

Why measure R_{xo} is important?

The zone invaded by mud filtrate may affect drastically the resistivity measurment so, the knowledge of the flushed zone resistivity, R_{xo}, is important for several reasons.

- when the invasion of the reserroir is moderate to deep, the knowledge of R_{xo} allows the correction of the deep resistivity measurments for the influence of the invaded zone

- یکی از روش ها برای محاسبه S_w نیاز به $\frac{R_{xo}}{R_t}$ دارد

- با داشتن R_{xo} و R_{mf} می‌توان S_{xo} را بدست آورد و با استفاده از رابطه Archie در flushed zone می‌توان ϕ را بدست آورد

Subject:
Date

$F = \frac{a}{\phi^m}$ تابع سازند F

$POI = \phi (S_{no} - S_w)$

$t = \left(\frac{S_{no} - S_w}{1 - S_w} \right)$

a) Micro log (ML)

non-focused device

non-focused دستگاه

ML: یک الکترود فرستنده در مرکز و دو گیرنده در بالا پایین و دارای spacing کم micro-inverse $A_0 M_2$ و فاصله‌ی دو گیرنده هم micro-normal $M_1 M_2$ می‌باشد

current emitting A_0, two receiver electrodes M_1, M_2

spacing between electrodes are 1in

since $R_{mc} < R_{xo}$, the micro-inverse will read less than the micro-normal opposite permeable zones.

Subject:
Date

correction for resistivity log Rxo-1 8 in. bore diameter

Micro log (ML)

$\frac{R_{1x1}}{R_{mc}}$ and $\frac{R_{<}}{R_{mc}}$ → hmc, Rxo

Micro lateral log (MLL) focused device

The principle is the same as LL7

The electrode array is mounted on a oil filled rubber pad

The spacing is diameter of a circle passing between M_1 and $M_<$

Vertical resolution is about 1.7"

Depth of investigation is about 1to2"

Mud cake has important effect on resistivity readings

Measured resistivity is close to Rxo

Subject:
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در حالتی که MLL خوب کار میکند، مقاومت بین mudcake و flushed خیلی تفاوت داشته باشند در اینصورت ML خوب کار نمی‌کند و MLL بهتر است

از MLL، PL، MSFL می‌توان mobility، POI، f، رابست آورد

correction MLL: mud cake correction R_{xo} - ۲

Subject:
Date

Micro proximity log (PL)

PL works on the same principle as the LL-3 but uses rectangular electrodes with a common centere, mounted on a solid rubber pad, wider than the MLL pad

It has a deeper depth of investigation and larger vertical resolution than the MLL

vertical resolution is about 6 in

PL is designed to work in fresh mud

correction for resistivity log R_{xo}

Micro proximity log PL - mud cake correction

Micro SFL log (MSFL)

This is a small-scale SFL array, mounted on a

Subject:
Date

flexible rubber pad. It has two advantages over the MLL and PL:

- It is less sensitive to the mud cake than the MLL, and reads shallower than the PL
- It can be combined with other tools, such as the DLL, while the MLL or PL requires a seprate run (and therefore more rig-time and risk of sticking)

correction for resistivity logs

invasion correction R_{int-gb}

R_t, R_{xo} can be found for R_{int-gb} chart

LLs, LLd, micro resistivity ⟶ d_i, R_{xo}, R_t

اگر MSFL بین LLs و LLd باشد یعنی شعاع رخنه زیاد است

اگر MSFL کمتر از LLd باشد یعنی شعاع رخنه کم است

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Resistivity log application

1. reservoir detection

2. determination of the fluid nature

3. water saturation determination

4. Porosity evaluation

$F = \frac{R_o}{R_w} = \frac{R_{xo}}{R_{mf}}$ $F = \frac{a}{\phi^m}$

5. determination of the water resistivity

R_{xo}: مقاومت کل سنگ در ناحیه flushed

فرض رابطه‌ی بالا اینکه است که ناحیه‌ی flushed صددرصد اشباع از mud filtrate باشد

تفسیر لاگ: جاهایی که هر سه نمودار LL8, ILd, ILm بر روی هم منطبق است یعنی mud invasion نداریم و تقریباً shale base line می‌باشد

چون LL8 بیشتر است پس یعنی وجود آب در ناحیه flush می‌باشد

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چون از IL استفاده شده، پس گل باید نفتی باشد

وقتی ILd , ILm نزدیک هم باشد یعنی این معنی است که mud

invasion کم می‌شود

مقاومت در لاگ را اگر منطقه خاصی مدنظری نباشد یا مقدار ماکزیمم را می‌گیریم

یا یک مقدار متوسط را می‌گیریم

Subject:
Date

Fundamentals of radioactive welllogging

density
Gamma - ~~porosity~~ - Neutron

passive active

Radioactivity

Stable Atom:

one which has equal number of protons, neutrons and electrons.

Radioactivity: A property possessed by some elemnts of spontaneously emitting alpha particles, beta particles and gamma rays as their atomic nuclei dis integrate.

Types of emmissions

- Alpha particles:

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Date

- positively charged particle with 2 neutrons and 2 protons (nucleus of the atom)
- easy to stop by a thick cloth

☐ Beta particles

two kinds.

β^- particle is an electron emitted from an unstable nucleus when one of its neutrons decays to a proton

β^+ particle is called a positron emitted from an unstable

☐ Gamma rays

- Mass less, chargeless bundles of high-frequency electromagnetic energy emitted when an atom passes from an excited state to a less excited state

Subject:
Date

- Travel at speed of light
- Referred to as photon when it has discrete quantity of electromagnetic energy
- penetrates to 15" rocks (1' of concrete)

Gamma ray interactions

Three principal gamma ray interactions:

- pair production (high energy)
- compton scattering (medium energy)
- photo electric Absorption (low energy)

Pair production

- phenomenon of conversion of GR into an electron and positron
- GR must have atleast 1.02 Mev

Subject:
Date

- Dominates the high energy interaction (10 MeV and up)

2. Compton scattering

- scattering of GR from an orbit

Subject:
Date

- scattering of GR from an orbital electron
- GR loses energy and e^- ejected from atom's orbit
- Vs keV < energy range < 1-MeV
- Dominates the medium energy interaction

Gamma ray interaction

gamma rays starts out with a given energy which is either lost through pair production, or undergoes compton scattering until the energy is sufficiently low to be absorbed by photo electric absorption

Subject:
Date

Gamma ray logging

اولین لاگ های غیر الکتریکی در صنعت نفت و دارای کاربرد های زیادی می باشد.

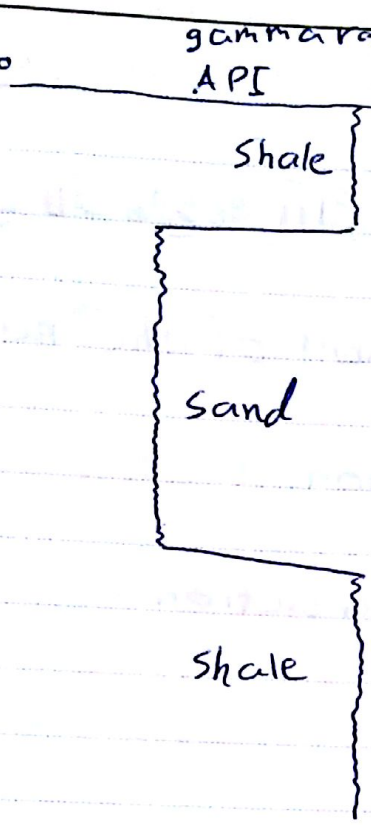
The gamma ray log is a measurment of the natural gamma radiation in the formation

three principle gamma ray interaction

- pair production
- compton scattering
- photo electric Absorption

Natural gamma rays information experience successive compton scattering collisions, losing energy until they are finally absorbed by some atoms via the photoelectric effect.

Subject :
Date



از ۵۰-۱۵۰ یا ۲۰۰-۰

در برابر Shale عدد بالایی خواهد خواند و در برابر Clean sand یک عدد پایین را خواهد خواند و در برابر Shaly sand یک عدد بین Min و Max خواهد خواند که می‌توان حجم Shale موجود را بدست آورد برای limeston یک عدد پایین می‌خواند حتی پایین تر از sand چون sand دارای کانی هایی می‌باشد که پرتو گاما از خود گسیل می‌کنند

limeston	۸-۱۵ API
Dolomite	۱۰-۲۰
sand stone	۱۰-۳۰
Siltstone	۳۰-۸۰
shale	۸۰-۱۴۰

گرده های آتشفشانی چون دارای مواد رادیو اکتیو می‌باشد عدد بالا را نشان می‌دهد

Subject:
Date

The GR log has a structure similar to the sp trace a low reading in the clean zone and a high reading in an apparently shaly zone

The biggest feature of GR log is that it can be run in almost any logging condition including

- ☐ cased wells
- ☐ open holes drilled with air
- ☐ open holes drilled with water based muds
- ☐ open holes drilled with oil based or fresh muds

source of natural radioactivity

we shall first address the question of the origin of this natural radiation

The source of all significant gamma ray activity

Subject:
Date

in sedimentry rocks is attributed to three naturally occurring radioactive isotopes potassium ^{40}K, thorium ^{232}Th, and uranium ^{238}U

Note: The largest source of formation radio activity is potassium in the earth's crust

two types of devices are routinely used for determining formation radio activity

Natural gamma tool (GR, SGR, CGR)

uses a simple gamma ray detector to measure the total radio activity on formation

Spectral gamma tool (NGS)

additionally quantify the concentrations of the radioisotopes present.

Subject:
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note: two types of devices have similar depths of investigation and suffer from minor environmental effects

Gamma ray energies

Factors affecting GR curve:

- Hole diameter
- Barite, Bentonite, KCl mud
- Casing cement

correction charts are available...

GR log application

- identification of lithology
- correlating zones from well to well
- estimation of the volume of shale (V_{sh}) present in the formation

Subject
Date

correlating zones from well to well

estimation of the volume of shale (V_{cl}) present in the formation

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

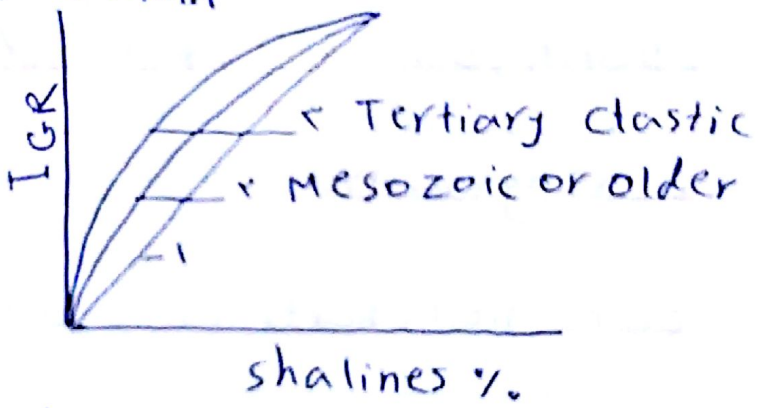
I_{GR} = GR index

$$V_{sh} \leq (V_{sh})_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

$V_{sh} = I_{GR}$

$V_{sh} = 0.33(2^{2 I_{GR}} - 1)$

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



source of natural radio activity

Note: The clay minerals are primarily responsible for two sources of radioactivity, potassium and thorium, associated with most shales

Subject:
Date

Uranium, because of its solubility is easily tranported from the site of clay mineralformation It is associated with the organic matter in the shales rather than the clay minerals

CGR : Thorrium + potasium (Th + k)

GR(SGR) : total gamma ray (Th + K + U)

The CGR curve is more consis tent with the knowledge that this is a largely clay-free zon

Identify the clay types

Subject :
Date

caliper log

used to measure the size and shape a borehole

various types of caliper log tools:

mechanical caliper

Ultrasonic caliper _ An ultrasonic transducer scans around the bore hole walls and the reflected travel time is converted to the distance between the sound and the wall

The simple mechanical caliper measures a vertical profile of hole diameter. It has two moving arms which are pushed the bore hole wall. The movement of these arms is recorded as an electrical

Subject :
Date

In the 4 arms dual caliper tool the two opposite pairs work together to give the bore hole diameter in two perpendicular directions

An example of a 4 arm tool: borehole geometry tool (BGT) ...

bit size برای تعریف دقیق تر log قطر چاه بدست می آید دو نوع است،

caliper, differential caliper

در این نوع bit size را صفر در نظر می گیریم و تغییرات قطر چاه را بدست می آوریم

This information is useful to estimate the amount of drilling mud in the bore hole and to estimate the amount of cement required to case the hole

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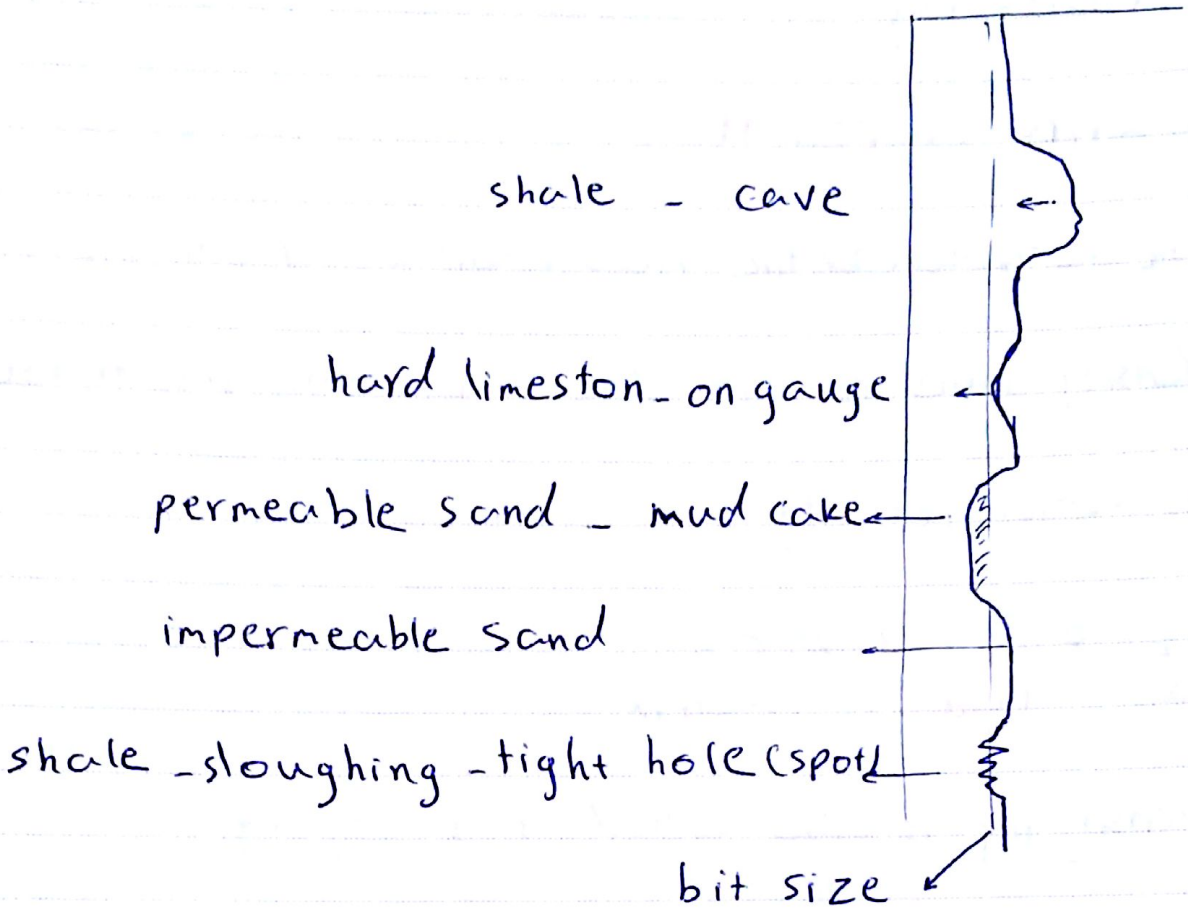

estimation of mudcake thickness

$$\frac{\text{bit size (diam)} - \text{caliper reading (diam)}}{2} = \text{mud cake thickness}$$

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Density log

o, serra Chapter 11

The motivation for the measurment of formation bulk density comes from its direct relationship with the formation porosity

$$\rho_b = \phi \rho_f + (1-\phi)\rho_{ma}$$

bulk — fluid — matrix

Density log is also called γ-γ logging

Tool emmits gamma-rays and measures gamma-rays returned from formation

principle: density tool measures formation density by emmitting gamma radiation and recording the amount of gamma radiation returning from the formation (attenuation of gamma-rays)

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as the tool is being raised

Permeable, Porous tool بر روی دیواره چاه می چسبد و در پایه های mud cake- تیر صفی دارد

Absorption equation

$$I = I_0 e^{-\mu \rho_e L}$$

I: intesity of gamma rays measured at the detector

I_0: intensity of gamma ray at the source

ρ_e: electronic density of the formation in the interval L

L: detector- source spacing

μ: constant depending on tool geometry, energy of gamma ray and detector characteristics

$$\ln I = \ln I_0 - \mu \rho_e L$$

The relation between ρ_e and ρ_b

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$\rho_b = \rho_e \left(\frac{Z}{A}\right) N$

Z = atomic number

A = atomic mass

N = avogadro's number (6.02×10^{23})

electron density index: $(\rho_e)_i = \frac{\rho_e}{N}$

Apparent global density: $\rho_a = 1.0V (\rho_e)_i - 1.1$

- for sands, limestons and dolomites (liquid saturated) : $\rho_a = \rho_b$
- for some substances or for gas-filled formations corrections have to be made
- Dense rocks have more rock atoms per unit volume than porous rocks. The denser and less porouse a rock, the more gamma ray energy willbe absorbed

PqPCO

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and less scattered gamma rays will return to the detector in the logging tool.

Density tool:

First tool: one detector

The measurments suffer from the effect of mud cake, its thickness and density

FDL: Formation Density Logging tool

(one detector)

Compensated tods: two detectors

To eliminate mud-cake effects

FDC= compensated formation density logging tool

(two detector)

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- modern devices incorprate two or more detectors in a housing that shields them from direct radiation from the source
- Note that the shorter spacing detector has less density resolution or sensitivity than the farther detector. generally the longer spaced detector, with its larger depth of investgation is taken as the formation density estimate

Depth of investigation

This is lower the higher is density of rock. It is small and doesn't go above 4in

It investigates essentially the invaded zone

Vertical Resolution

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For FDL correspond to the source_detector spacing (around 14 in)

For FDC is the distance between two detectors (about 10 in)

Measure point

For FDL is the midpoint of the source_detector

For FDC is the " " " two detector

density range: 2-3 $\frac{g}{cm^3}$

note: when mud cake is present; long spacing detector requires compensation or correction. This correction is traditionally reffered to as $\Delta\rho$

$\rho_b = \rho_{LS} + \Delta\rho$

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زمانی که ΔP صفر می‌شود یعنی ریزش دیواره، تشکیل mud cake ...

ندارید و ابزار با دیواره چسبیده است، اگر $\Delta\rho$ وجود داشته باشد می‌توان

poor bad contact with borehole wall. فهمید که اتصالاتی افتاده است، یا علت

B if the mud cake is more dense than the formation, then the counting rates decrease, and if the mud cake density is less than the formation density, then the counting rates increase.

آهنگ شمارش

یا سرعت

$$\rho_b = \phi\rho_f + (1-\phi)\rho_{ma}$$

ϕ corresponds as total porosity ϕ_t

$$\phi_D = \frac{\rho_b - \rho_{ma}}{\rho_f - \rho_{ma}} \qquad \phi_{density}$$

ρ_b = log reading of bulk density

Thus, to estimate porosity properly, two important

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Parameters must be known:

- The rock matrix (or gain) density ρ_{ma}, and
- the density of the saturating fluid ρ_f

$$\rho_{ma} = \sum_{1}^{n} V_n \rho_{man}$$

$$\rho_f = S_h \rho_h + S_{xo} \rho_{mf}$$

$$S_h + S_{xo} = 1$$

The effect of shale

- the influence of shale for density logs is much less than for neutron logs

The density of dry clays is somewhere around that of quartz and so they have approximately the same effect within the matrix

- if their density is very different from the other

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minerals composing the rock. we have the following equation

$$\rho_{bc} = \rho_b + V_{sh}(\rho_{ma} - \rho_{sh})$$

ρ_{bc}: shale corrected bulk density

ρ_b: log reading of bulk density

ρ_{ma}: matrix bulk density

ρ_{sh}: shale bulk density

V_{sh}: shale percentage

Water.

The tool was calibrated with fresh water. if the rock is porous and invaded, the fluid in the zone investigated by the tool is mainly mud filtrate As the density of this can vary with temprature and pressure as a function of its salinity

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we need to make corrections in the interpretations

Hydrocarbons

hydrocarbon density, especially gas, are less than that of water which means that the same formation full of gas appears much lighter and therefore more porous than if water-saturated

DPHI: density porosity curve

chosen values for ρ_{ma} and for the density of the saturating fluid ρ_f

Por_5

combining the density with other measurments is the best way to determine the porosity

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Litho-density,

knowledge of the matrix density of the rock formation is an important factor in converting the measured density to porosity

Measurment of the average atomic number or a related parameter P_e, would be valuable

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

This is a new generation of density tool which provides additional lithology information

when photoelectric absorption is included in the calculation, it is necessary to take into account the fact that at each gamma ray collision

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there is a probability that the gamma ray willbe absorbed rather than scattered

The probability of photo electric absorption depend on the gamma-ray energy and on the atomic number Z of the scattering material.

The absolute probability of a photo electric interaction is described by the atomic cross section (τ)

For the most common sedimentry rocks and energy of gamma ray used.

$$\tau = 1.1 \frac{Z^{4.4}}{E_\gamma^{1.1}} \quad \frac{\text{Barns}}{\text{atom}} \rightarrow$$

واحد سطح در فیزیک هسته‌ای (سطح مقطع که احتمال اینکه از اتم گاما با آن برخورد می‌کند)

Definition of the photo electric absorption index

The photo_electric absorption cannot be

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easily described

It is convenient to define photo-electric absorption index (P_e) which is proportional to the photoelectric ~~absorption index~~ cross section per electron with the energy dependance suppressed.

P_e is well approximated by:

$$P_e = \left(\frac{Z}{10}\right)^{9.8}$$

page 207 serda book table 12-1

لاگ‌های SP برای لایه‌های ضخیم می‌باشد، لایه‌های آهکی تشکیل‌های شیلی می‌دهد.

LDT (Litho-Density tool description)

The schlumberger LDT tool is composed of

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1. 137Cesium source which emits a constant flux of gamma ray with the energy of 661 kev
2. A near detector (short_spacing detector)
3. A far detector (long_spacing detector)

Radius of investigation, similar to FDC

Vertical Resolution

LDT long spacing being smaller than FDC, the vertical resolution is better.

Interpretation of Pe

- in normal logging circumstances, the Pe log readings should range between 1 and 6

Pe for:

1.8 for quartz 3.1 for dolomite 5.1 for calcite

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So, in the simplest of circumstances, it is useful in distinguishing sand from limeston or dolomite.

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Part 12,

Neutron logs: first neutron logging tool was the first device used to estimate formation porosity

density, neutron, sonic

chapter 8 o, serra

Neutron logging tools

CNL tool (compensated Neutron Logging tool)

- Neutron tools use a radioactive source, such as Pu-Be ... (to be continued)
- the tools bombards the rocks adjacent to the well with high speed, high energy neutrons
- if a neutron collides with a large rock atom the atom (e.g. carbon) will bounce the high speed

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neutron back with almost no loss of energy (fast-moving neutrons will bounce back as the rock is bombarded)

- if a neutron collides ...
- each rock is bombarded with a certain number of high-speed neutrons. either the slow neutrons or number of gamma rays is counted.

if the tool consist of a neutron source and neutron detectors, we refer...

α β γ neutron $\longrightarrow$

depth of penetration increase

neutron log can be run in open and closed hole because neutron can penetrate steel

در محیط لاگ نوترون در open hole استفاده می‌شود چون لاگ porosity

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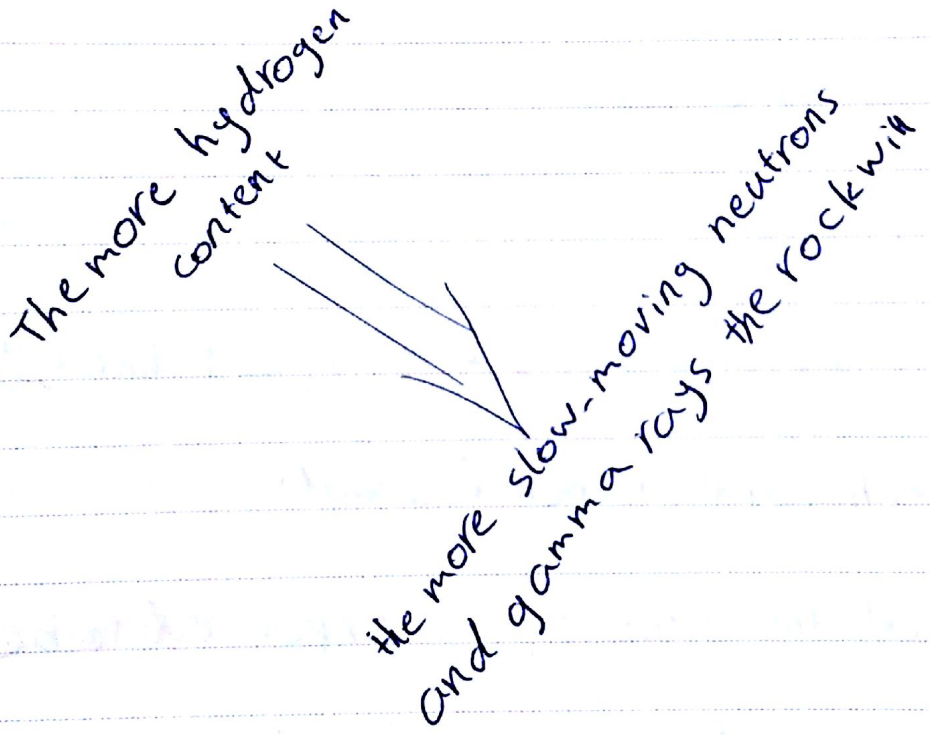
هم همزمان نازاست .

Basic idea of neutron porosity log

The measurment principle is based on the fact that:

Hydrogen is very efficient in the slowing-down of fast neutrons.



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since hydrogen in the formation is sometimes in the form of hydrocarbons or water and tends to occur in the pore spaces, the correlation with formation porosity is easily made

The more porous the rock, the more slow neutrons and gamma rays willbe emitted and counted

Nphi → تخلخل حاصل از نوترون

Dphi → دنسیتی " " "

هردو در limestone اشباع از آب شیرین کالیبره می شوند

Why is the Nphi curve, labeled sand?

assumes that the lithology is expected to be predominantly sandstone, itwill read correctly only in sandstone formations.

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Why does the scale for Nphi seem to be presented backwards? (-.15 - .45 v/v)

It has been traditional to present a dynamic range of $1 \frac{g}{cm^3}$ on the density trace across the full track, It is easy to show that a change in bulk density of $\frac{1g}{cm^3}$ in a water-filled formation corresponds to a porosity change of about 60 units (p.u.)

consequently, the neutron trace is ...

lithology effects

The limeston-calibrated tool, for sandstone the tool would read lower than the true porosity. For the case of a dolomitic formation would read a slightly larger porosity

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Shale effect:

Because shales always contain some bonded water, the neutron log will always give a higher apparent porosity reading than actually exists.

Gas effect:

The hydrogen content of oil and water is about equal, but is lower in HC gas, thus the neutron log may give too low porosity reading in the gas reservoirs. (This fact can be turned into an advantage!)

gamma ray ⟶ sand

resistivity ⟶ brine and hydrocarbon

density ⟶ gas, oil, water