Chapter 2 Identification of Reservoirs and Reservoir Fluids

- **Identification permeable beds**
- **Inferring reservoir fluids**

Geological logging: First hand information

Formation testing: Evaluation oil, gas, water bed; Getting dynamic parameter, K, P

Well logging: Identification hydrocarbon reservoirs; Calculation Formation parameter

Well logging is one of the most common and most important methods

for stratigraphic comparison,

for tectonic analysis,

for pay evaluation.

It is the process of recording various physical, chemical, electrical, or other properties of the rock/fluid mixtures penetrated by drilling a well.

Well logging provides information that helps to

- **Determine types of formations such as sandstone, limestone, shale, or dolomite, and their thickness as well as the depths of each formation top and bottom.**
- **Other information that is available includes formation temperature, porosity, permeability, the presence of oil or gas, and much other valuable data.**

Chapter 2 Identification of reservoirs and reservoir fluids

What? Why? How?

Section 1 Main Well Logging Methods

Section 2 Identification of Hydrocarbon Reservoirs in Clastic Sections

Section 3 Identification of Hydrocarbon Reservoirs in Gypsum and Salt Rock Sections

Section 4 Identification of Low Resistivity Hydrocarbon Reservoirs

Section 5 Identification of Fractured Hydrocarbon Reservoir in Carbonate Sections

Section 1 Main Well Logging Methods

Well logging is one of the most common and most important methods to research petroleum engineering.

Electric logs ----resistivity, spontaneous potential ,
micrologs, induction electrical log,

Acoustic log ----interval transit time

Radioactivity log---- gamma ray logging,
neutron logging

Other well logging ---- caliper log,
dipmeter survey
directional log

Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Electric logs

It is one of the earliest logging methods used.

The electric log, or E-log, often gives a good indication of formation resistivity and invasion,

Many oil and gas deposits have been discovered using electric logs.

Main Well Logging MeSection 1 thods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Electric logs

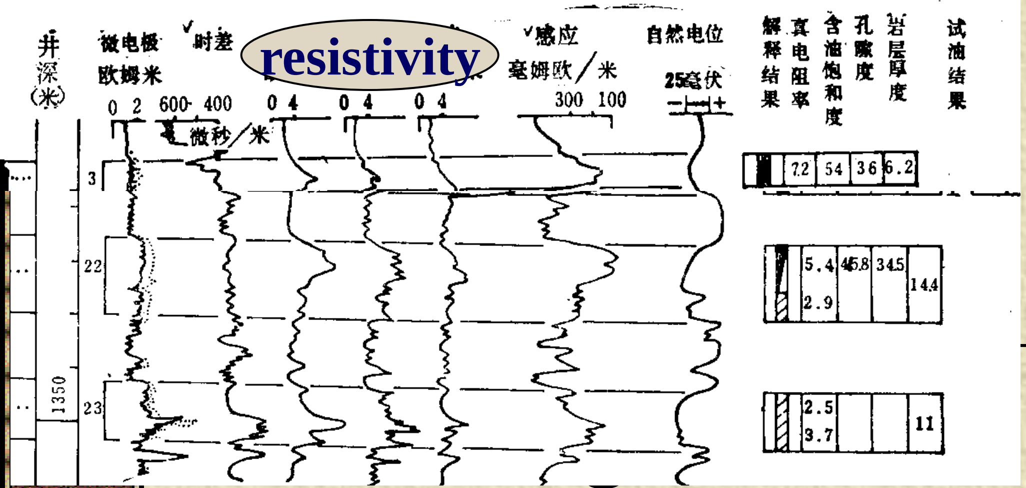
Electric logs are always run in an **open, uncased borehole** that is filled with water. The instrument, which is lowered into the hole by wireline and insulated electrical cable.

resistivity,

spontaneous potential ,

micrologs,

induction electrical log



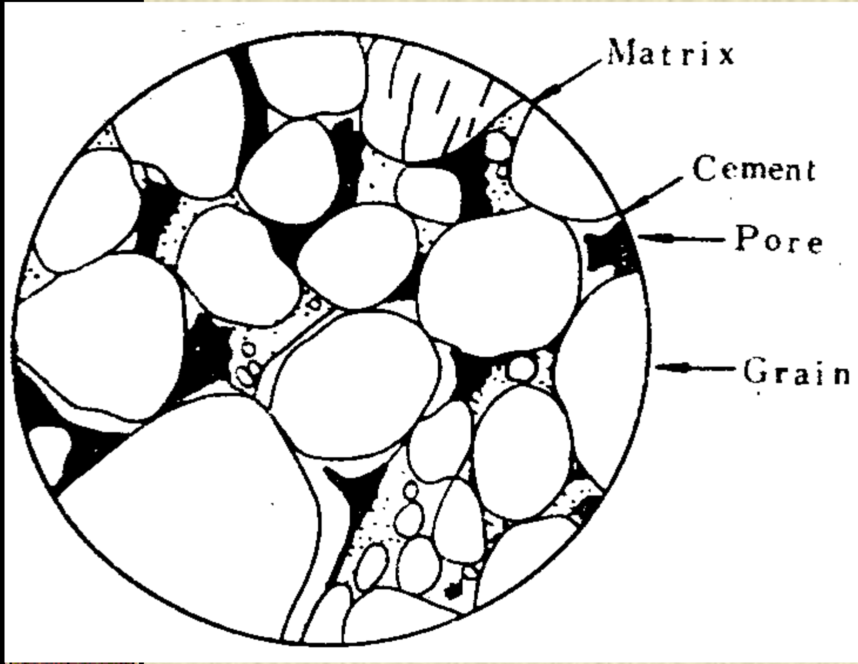
Main well logging Methods

clastic

Sandstones are essentially **silicon oxide** and have **high resistivities** if they are completely dry and free from conductive materials.

Distilled water also has a high resistivity. However, when **dissolved salts** and other **impurities** are added, it becomes more conductive. This means that when sandstone contains impure formation water, its resistivity will vary with the amount and salinity of the water.

Oil is a good insulator with high resistivity, and when added to the formation water will change the formation’s resistivity readings.



Section 1
Main Well Logging Methods

Electric logs

When sediments are deposited and compacted, they do not form a solid mass of rock. Spaces exist between the grains that are called voids or pore spaces.

These represent the porosity of the formation. Porosity affects the amount of fluids(water, oil) that the rock can hold, and thus the formation resistivity factor is related to this void space.

Main well logging Method

Archie's equation

George Archie pioneered studies in resistivity during the early days of log interpretation research.

Archie's equation

$$F = Ro/Rw = a \cdot \Phi^{-m} = a/\Phi^{m}$$

$$I = Rt/Ro = Rt/(FRw) = b/S_w^{\,n}$$

$$Sw^{n} = b * Ro/Rt$$

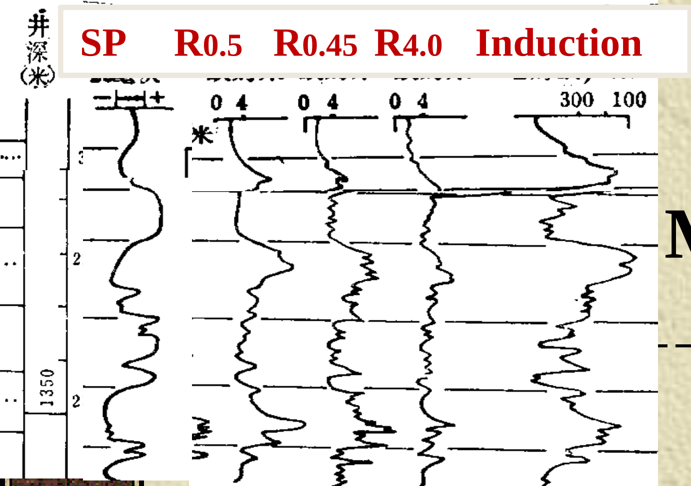
F----formation factor

Rw----formation water resistivity

Φ----Porosity,%

Rt----formation resistivity

Sw----water saturation



Main Well Logging Methods

- Electric logs
- Acoustic log
- Radioactivity log
- Other well logging

Resistivity

The units of resistivity may be measured with an ohmmerter (Ohm)

The readings recorded at the surface.

The electric log usually consists of four measurements,

spontaneous potential (SP)

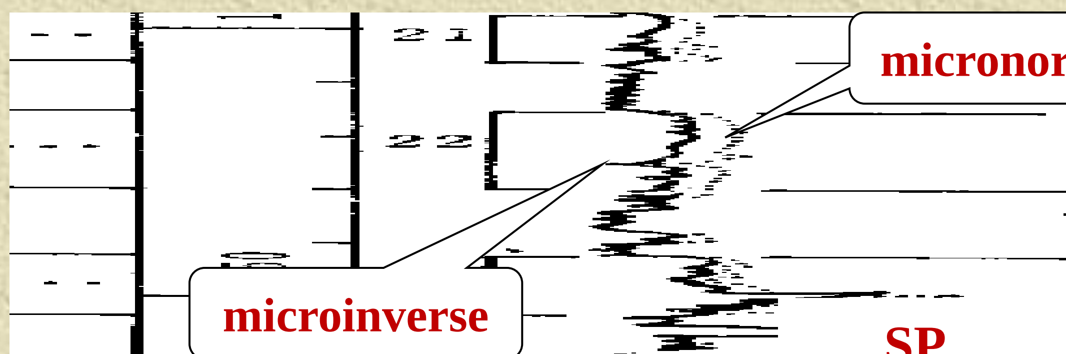
three resistivity measurements with different depths of investigation

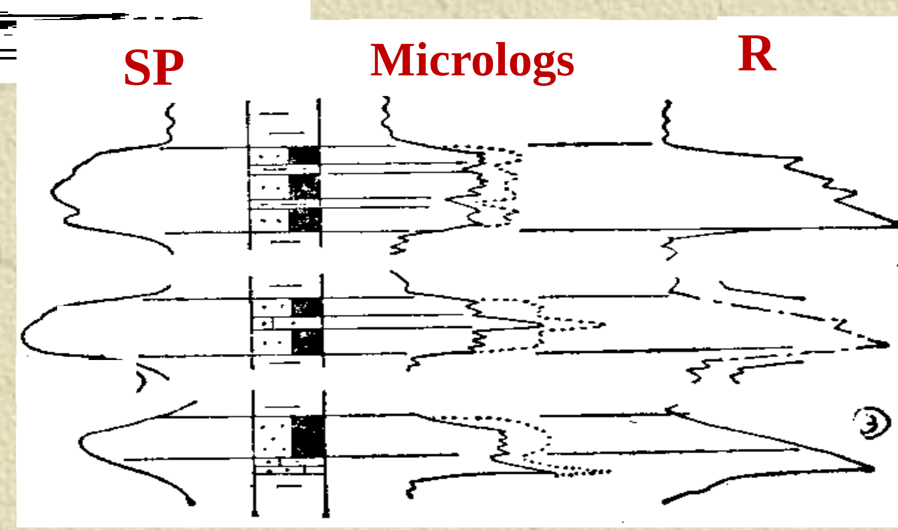
Section 1
Well logging Methods

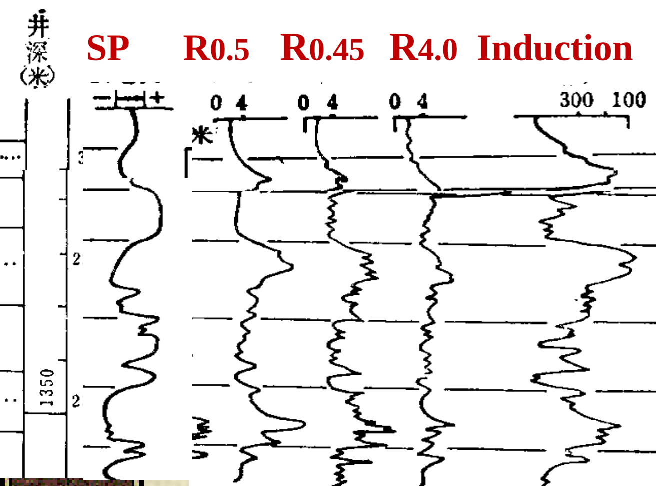
Electric logs
Acoustic log
Radioactivity log
Other well logging

Micrologs

Micrologs were developed to locate and define thin permeable zones.







Section 1 Main Well Logging Methods

Induction electrical log

Induction-electrical logs **are run with wireline equipment in an openhole. Induction-Electrical logs usually record three tracks.**

Track 1 is for the spontaneous potential (SP) curve. The SP curve is a graph that shows the electric potential, or voltage, that underground formations generate. The SP curve is plotted against depth in the borehole.

Track 2 records resistivity and is plotted against depth.

Track 3 records conductivity and is plotted against depth.

The normal depth scales are 2 in. = 100 ft. for a regular log and 5 in. = 100 ft. for a detailed view. For deep holes, a depth scale of 1 in. = 100 ft. is used

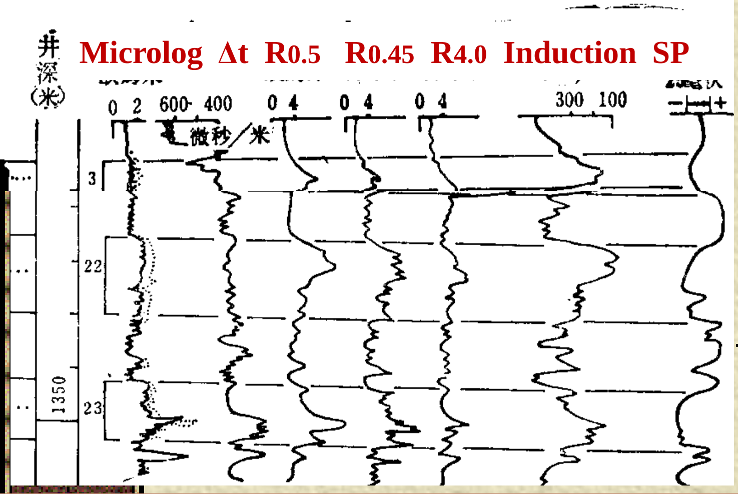
Main well logging Methods

Spontaneous Potential (SP) Log

The *Spontaneous Potential (SP) log* is a record of the naturally occurring voltage, or potential, caused when the drilling mud comes in contact with the formation. This resulting voltage is due to an electrochemical action caused by the differences in salinities of the various fluids.

Since this voltage occurs naturally, it is termed *spontaneous*.

The SP values are very small and they are measured in *millivolts* (MV), which are thousandths of a volt.



Main well logging Methods

Spontaneous Potential (SP) Log

Usually the Spontaneous Potential (SP) line on the log shows a more or less **straight line opposite impermeable shales,** and will **show peaks to the left opposite permeable strata**.

The shapes and amplitudes of the peaks may be different according to the type of formation.

The variations of shapes and amplitudes are related to the lithology.

The main uses for the SP curve ----

- To detect permeable beds, that is sand vs. shale formations
- To locate the boundaries between beds
- To obtain good values for formation water resistivity
- To correlate **equivalent beds** from well to well.

Main well logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Spontaneous Potential (SP) Log

The SP deflection is measured with respect to the shale base line.
(reference line ----extreme positive side of the SP curve, a straight vertical line)
The maximum SP deflections toward the negative side on the log are opposite permeable formations.

The SP curve is important in geological correlation because the shapes of these curves in different wells for certain geologic horizons will be comparable.

Section 1 Main well logging Methods

Acoustic log

The *acoustic, or sonic* log was originally developed as an aid for interpreting seismic exploration data.

However, it proved to be so effective in determining porosity that in many areas it became the standard porosity tool.

It measures the depth versus the time it takes for a sonic impulse (a *compressional* or *P-wave*(压缩波，纵波，P波) to travel through the rocks and fluids of a formation. Their speed of travel depends on the type of materials, or mixture of materials, they are passing through.

Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Acoustic log

The acoustic or sonic tool **uses sound waves to measure porosity.** Sound is energy that travels in the form of a wave, and this wave can travel in several different forms.

Compressional waves are the most common form because they are the first wave to arrive, and thus are called P-waves or primary waves.

A second type of sound wave is the *shear wave* or *S-wave*. It is slower than the P-wave and it must be in a solid medium in order to transmit its energy.

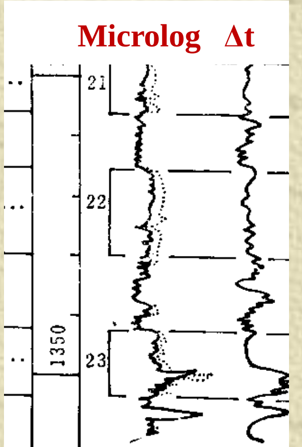
Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Acoustic log

The acoustic tool takes advantage of the fact that a sound wave travels at different speeds through different materials and at different speeds through mixtures of different materials.

By knowing the speed factor for each of the materials likely to be present in underground formations, it is possible to **calculate the amount of each material present**.

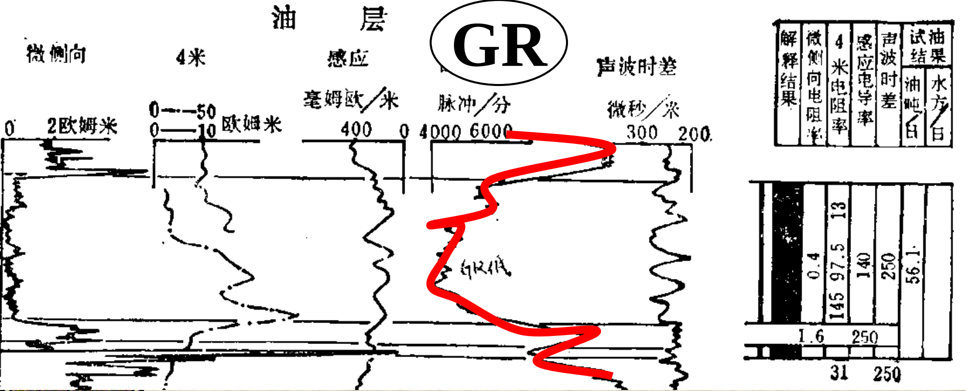


Section 1 Main Well Logging Method

Electric logs
Acoustic log
Radioactivity log
Other well logging

Radioactivity

Radioactivity logs, which may be run in either open or cased holes. The gamma ray and the neutron logs are radioactivity logs.



Main Methods

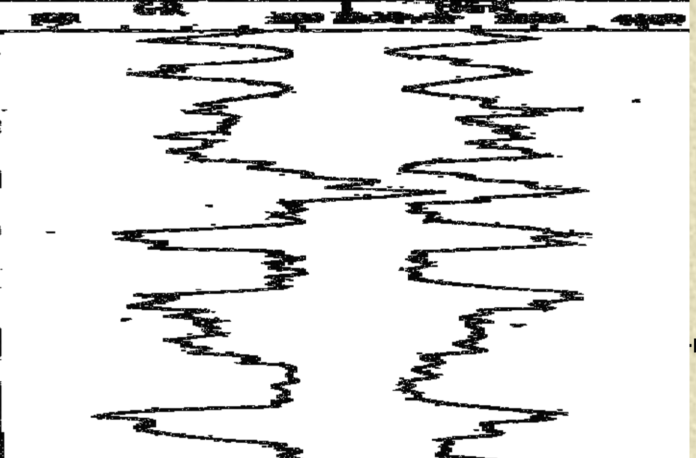
Gamma ray logging

Be run in cased or open holes

Natural radiation of unstable elements consists primarily of alpha, beta, and gamma rays. Of these, it is only practical to measure gamma radiation in a borehole. Gamma rays are typical forms of electromagnetic radiation. Some elements naturally emit gamma rays, which are distinctive in both number and energy.

Low gamma ray counts are related to non-shales.

High gamma ray counts are related to shales.



Electric logs
Acoustic log
Radioactivity log
Other well logging

Gamma ray logging

By measuring gamma ray intensity and plotting the data as a function of depth, a graph is obtained which shows varying formations.

It permits the sandstones to be distinguished from clays and shale.

Gamma ray and neutron logs are usually run on the same instrument and the gamma ray curve is recorded on the left side of the chart and the neutron curve on the right.

Neutron logging is normally a standard counterpart of the gamma ray log. The neutron log is obtainable in both cased and uncased boreholes and is usually recorded simultaneously with the gamma ray log.

Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Neutron logging

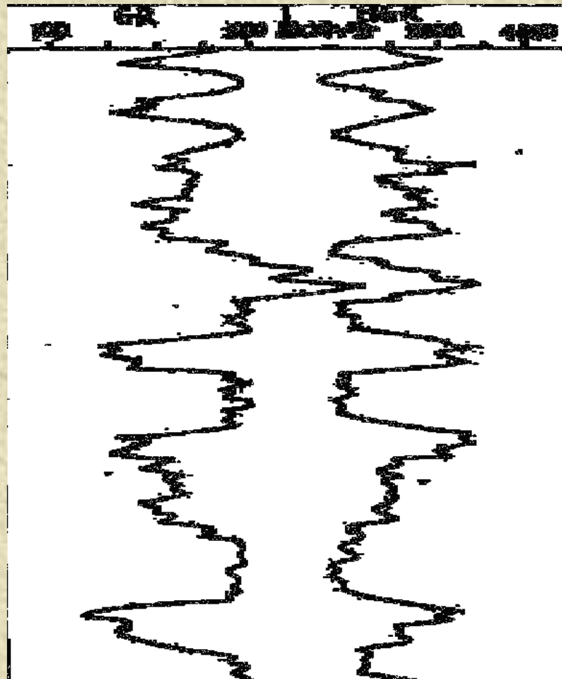
Neutrons exist in the nuclei of all elements except hydrogen. They are about the same mass as a hydrogen atom, but have no charge.

The neutron curve may be used to

evaluate lithology,

formation depths and thickness,

and the location of gas-fluid.



Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Density log

The density log is a good porosity measuring device, particularly for shaley sands. It provides a continuous record of variations in the density of the lithologic column penetrated by the borehole.

Most density logging devices simultaneously record a gamma ray log, a density log, and a caliper log, and thus usually called *GDC Surveys*.

Density log is very useful

Porosity correlates with density because the rock matrix must decrease in density as its porosity increases.

The density log variations within a uniform sandstone or limestone body represent increases and decreases of its porosity.

Caliper log

The *caliper log* measures the diameter of the borehole.

Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Directional Log

The *directional log* is a record of hole drift, or deviation from the vertical, and the direction of that drift.

There is no such thing as a vertically-true drilled oil or gas well. For many reasons, a directional log is necessary to insure that the producing formation is.

Much of today's drilling is not only purposely directional, but, in fact, horizontal. Many new tools, computer programs, and techniques have been developed to plan the path of the wellbore, calculation, and compare its actual location to the target location. The downhole instrument probe is contained within the drillstring and transmits its information by mud pulse telemetry to the drillsite computer and driller's readout station.

Section 1 Main Well Logging Methods

Electric logs
Acoustic log
Radioactivity log
Other well logging

Dipmeter Survey

The *dipmeter* is run to determine the direction and angle of formation dip in relation to the borehole

The instrument for measuring dip uses three or four contact electrodes equally spaced in a plane perpendicular to the wellbore. Each set of electrodes records a separate electric logging curve. By inspecting these curves, it is possible to correlate them, or to locate points that are common to each. If the bedding plane is not the same as the plane of the three electrodes, the curves will be displaced.

One of the major uses of the dipmeter log is to gain an idea of the geological structure from an exploratory well.

Chapter 2 Identification of reservoirs and reservoir fluids

What? Why? How?

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Section 3 Identification of hydrocarbon reservoirs in Gypsum and Salt Rock Sections

Section 4 Identification of Low Resistivity Hydrocarbon Reservoirs

Section 5 Identification of Fractured Hydrocarbon Reservoir in Carbonate Sections

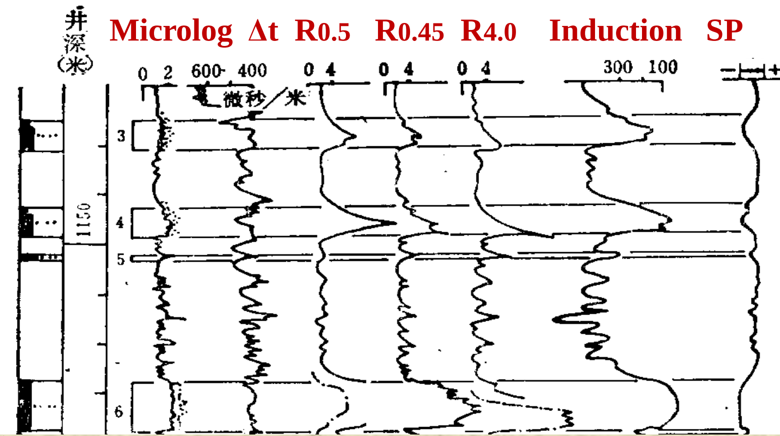
Section 2 Identification of Hydrocarbon Reservoirs in Clastic Sections

Clastic Section----Sand-Shale

clastic rock, detrital rock
clay rock, claystone

Feature
- Lithology
- Pore uniform distribution
- Fluids regular distribution
- Drilling fluids regular invasion
- Well logging data well

I. Identification of Reservoirs
II. Identification of Hydrocarbon Reservoirs
III. Analysis of Special Hydrocarbon Interval



Ⅰ. Identification Reservoir

1.SP (Spontaneous Potential): negative anomaly

2.MLL(micro electric logs): normal diviation

RaMN>RaML (micronormal > microinverse)

3.R (Resistivity) High resistivity

4.GR(Gamma ray logging) : Low gamma ray value

5.CAL (Caliper log): undergauge

II. Identification of reservoir fluids

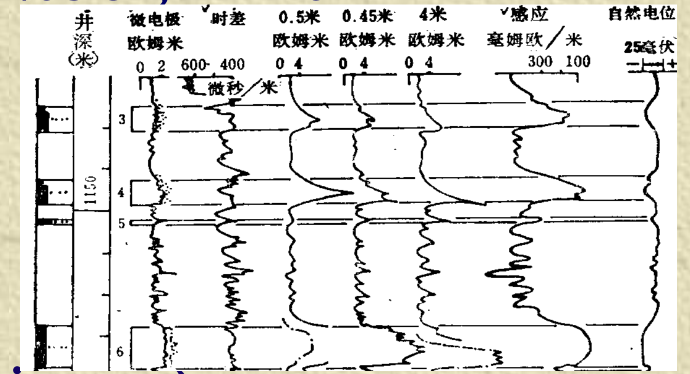
1.Qualitative interpretation

fresh water mud, Cm<Cw

Resistivity:

hydrocarbon reservoir----high R, decreased resistance invasion, Ri<Rt

water layer----low R, increased resistance invasion, Ri>Rt



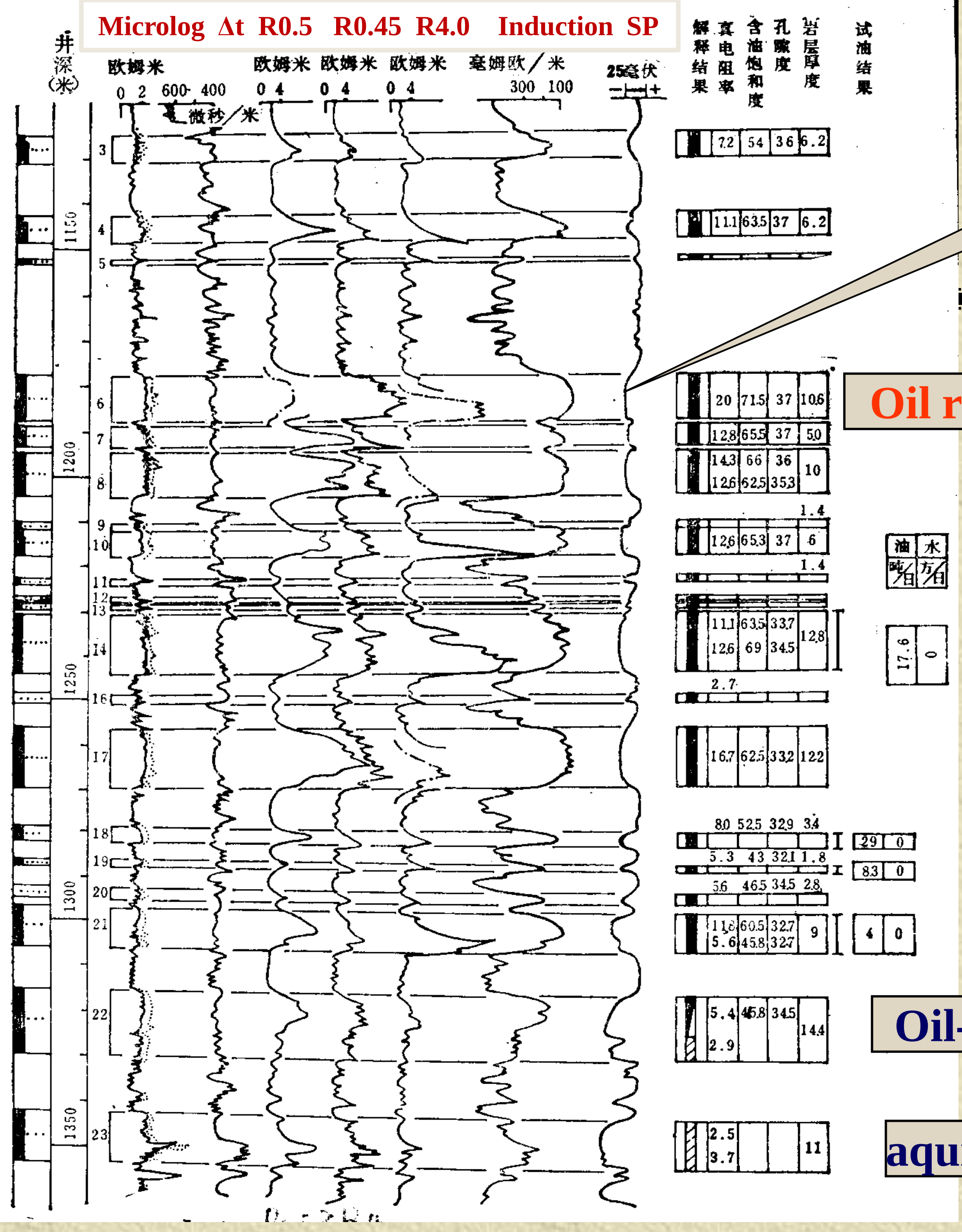
SP: water-oil-gas layer negative anomaly

Micro electric logs : Positive separation

Ra^{MN}>Ra^{ML} (micronormal > microinverse)

Acoustic log: gas-bearing formation , Cycle skipping high Δt

High interval transit time


Microlog Δt R0.5 R0.45 R4.0 Induction SP
井深(米)
欧姆米
微秒/米
欧姆米
欧姆米
欧姆米
毫姆欧/米
25毫伏
解释结果
真电阻率
含油饱和度
孔隙度
岩层厚度
试油结果
negative anomaly
Oil reservoir
Oil-water reservoir
aquifer

2. Fast-looking

Movable water method(S_w, S_{wi})

S_w---- Water saturation

S_{wi}---- irreducible water saturation

Hydrocarbon reservoir: $S_w = S_{wi}$, $K_{rw} \rightarrow 0$, $S_{mw} \rightarrow 0$

Aquifer: $S_w > S_{wi}$, $K_{rw} > 0$, $S_{mw} \neq 0$

K_{rw}: Water relative permeability

III. Analysis of Special Hydrocarbon Interval

1. Oil-water layer and aquifer with high resistance

2. Heavy oil with high resistance

1. Oil-water layer and aquifer with high resistance

According to well logging interpretation: Oil bed
Testing result: Oil-water bed or aquifer

Features: (1) Physics Property----High permeability

(2) Electric Property----High resistivity

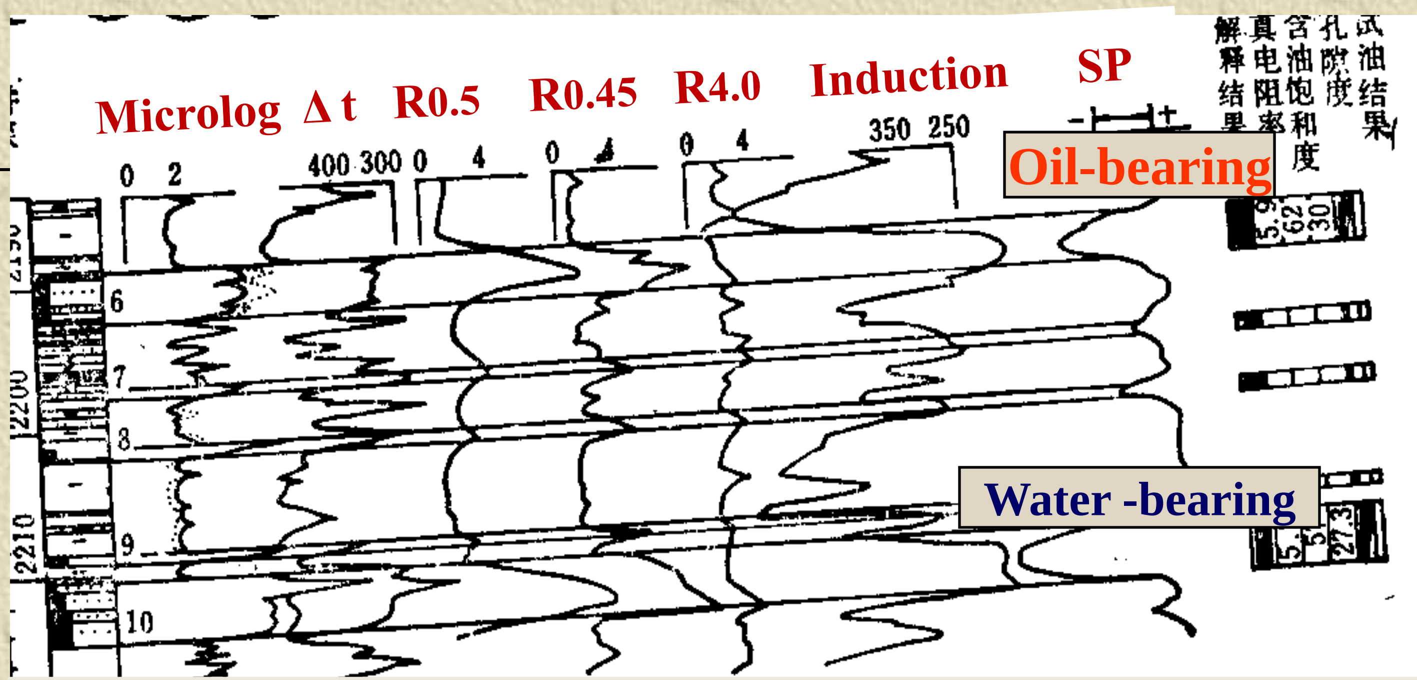
Under same R， So coarse grain size----aquifer

fine grain size----oil-water layer

Origin： Coarse grain size, High resistivity ,

Low irreducible water saturation

1. Oil-water layer and aquifer with high resistance



Oil-water layer and aquifer with high resistance

Layer 6 and 10 have similar R and So, but why layer 6 produces oil, layer 10 produces water?

The median grain diameter of layer 6 is 0.195mm, and layer 10 is 0.247mm, respectively

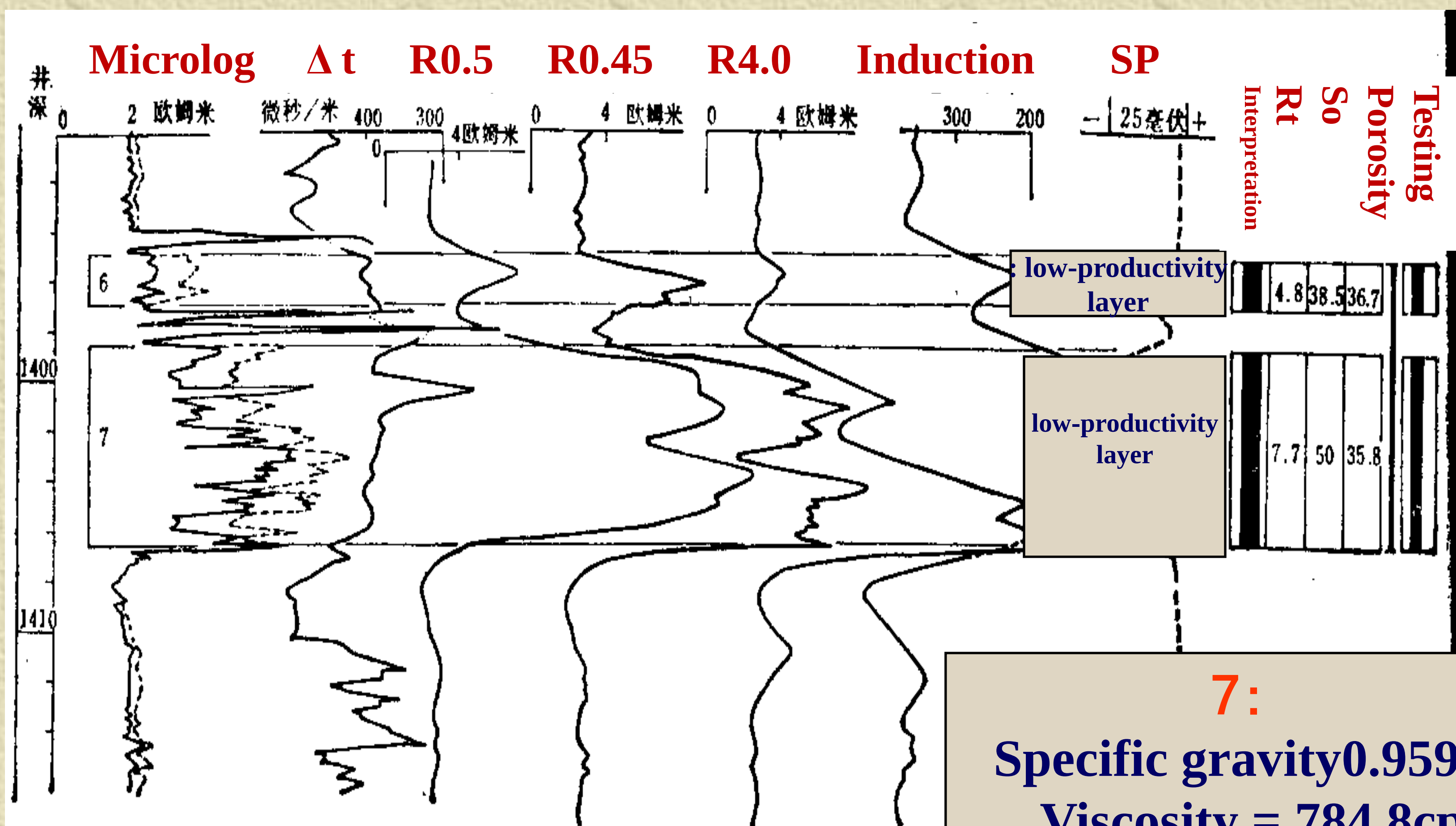
2. Heavy oil with high resistance

Heavy oil: High specific gravity,
High viscosity,
High flow resistance,
High residual oil saturation（Sor）

Type	Viscosity mPa s	Density	Production Method
Conventional heavy oil	50-150	>0.9200	Water flood
	150-10000	>0.9200	Thermal recovery
Super heavy oil	10000-50000	>0.9500	Thermal recovery
Extra-heavy oil	>50000	>0.9800	Thermal recovery

Movable oil saturation(Smos)
Invaded zone water saturation(Sxo)
Undisturbed water saturation(Sw)

$$Smos = Sxo - Sw$$



Heavy oil with high resistance

7:

Specific gravity0.9598

Viscosity = 784.8cp

So = 50%

Heavy oil: low-productivity layer

III. Analysis of Special Hydrocarbon Interval

1. Oil-water layer and aquifer with high resistance

2. Heavy oil with high resistance

Chapter 2 Identification of reservoirs and reservoir fluids

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Section 3 Identification of hydrocarbon reservoirs in gypsum and salt rock sections

Gypsum and Salt Rock Sections: consist halite, gypsum, anhydrite, a little carbonatite and sand-shale mud

I. **Identification reservoir** (carbonatite, sand)

II. **Identification of hydrocarbon reservoir**

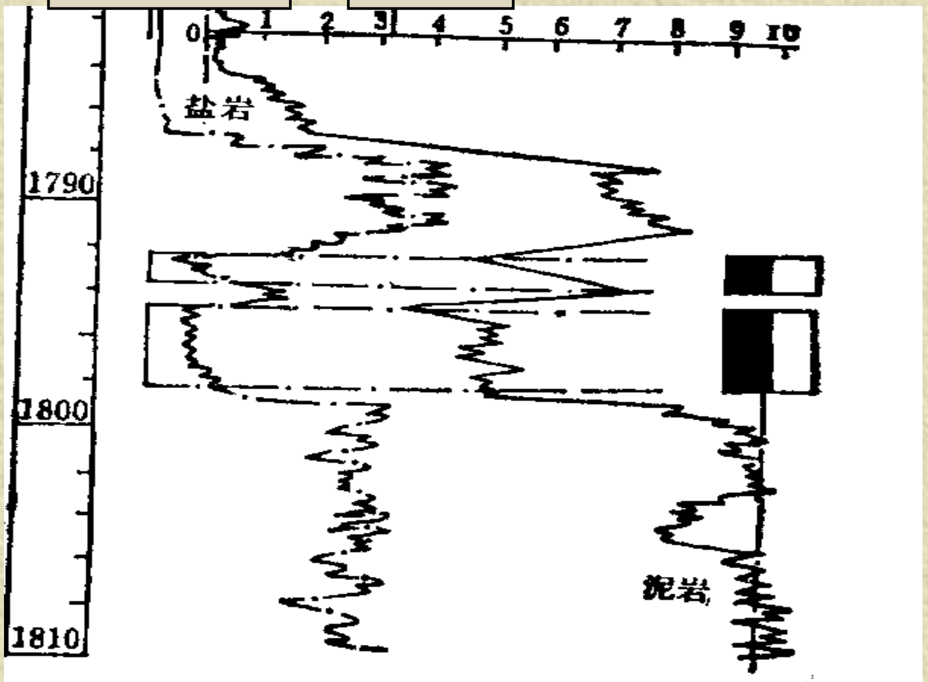
I. Identification reservoir

GR----permeable bed,

Microlaterolog define the depth and thickness of permeable beds

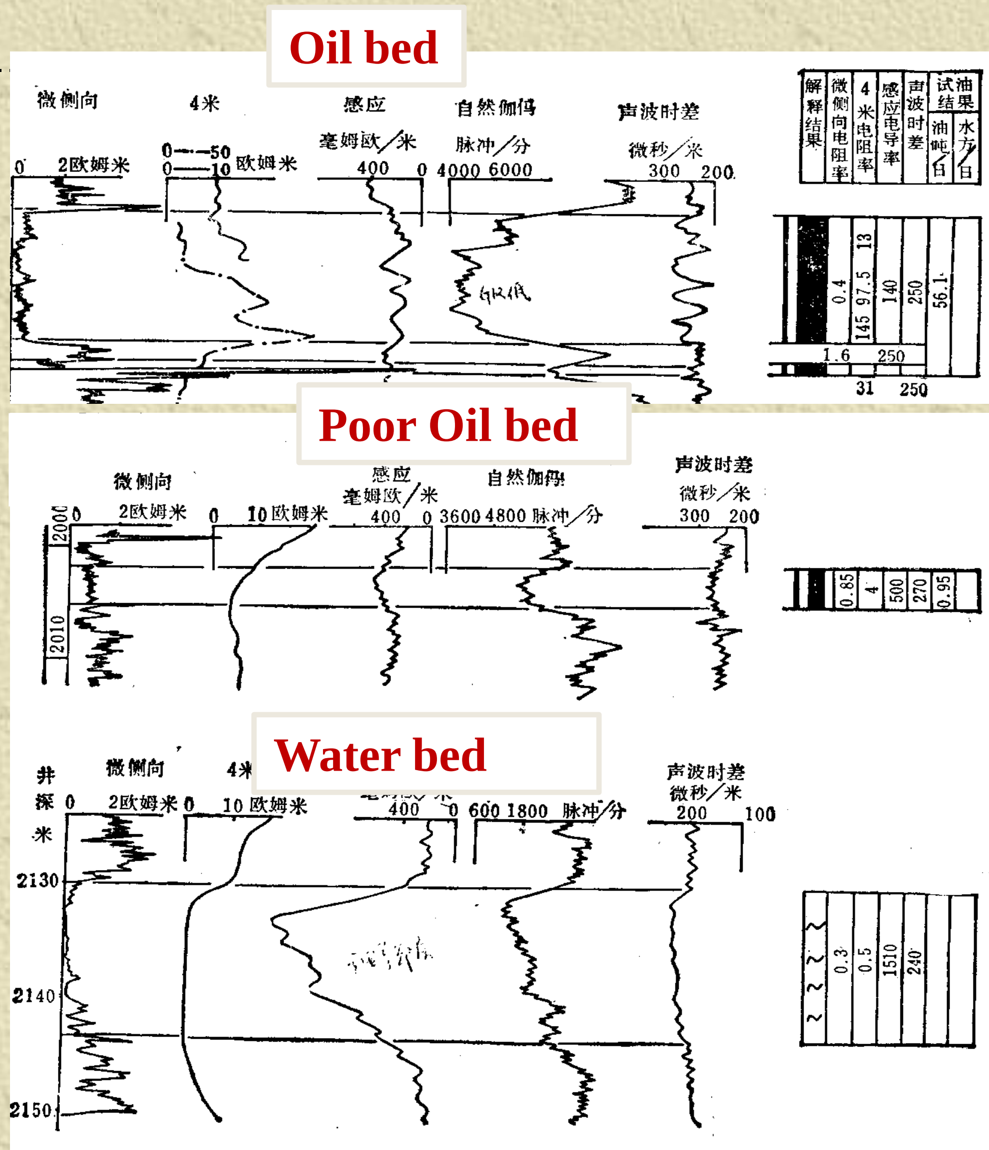
Microlaterolog

GR



Identification sand

II. Identification of reservoir fluids



Chapter 2 Identification of reservoirs and reservoir fluids

What? Why? How?

Section 4 Identification of Low Resistivity Hydrocarbons Reservoirs

Some low resistivity oil bearing reservoirs which have water saturation greater than 50% but don’t produce water have been found in many oil fields. That draws people’s attention to low resistivity oil reservoirs.

Low resistivity Reservoir

Water Saturation(Sw) **Sw≥50%，I≤ 3**

I. Low Resistivity Reservoir Features

II. Low Resistivity Reservoir Genesis

III . Low Resistivity Reservoir Identification

I. Low Resistivity Reservoir Features

1. Fine grain size, large specific surface, strong absorption ability, high irreducible water content；

   Membrane occluded water——related to adsorption
   Capillary occluded water----related to wettability and capillarity

2. Clay content high, leading to additional conductibility

   kaolinite, montmorillonite

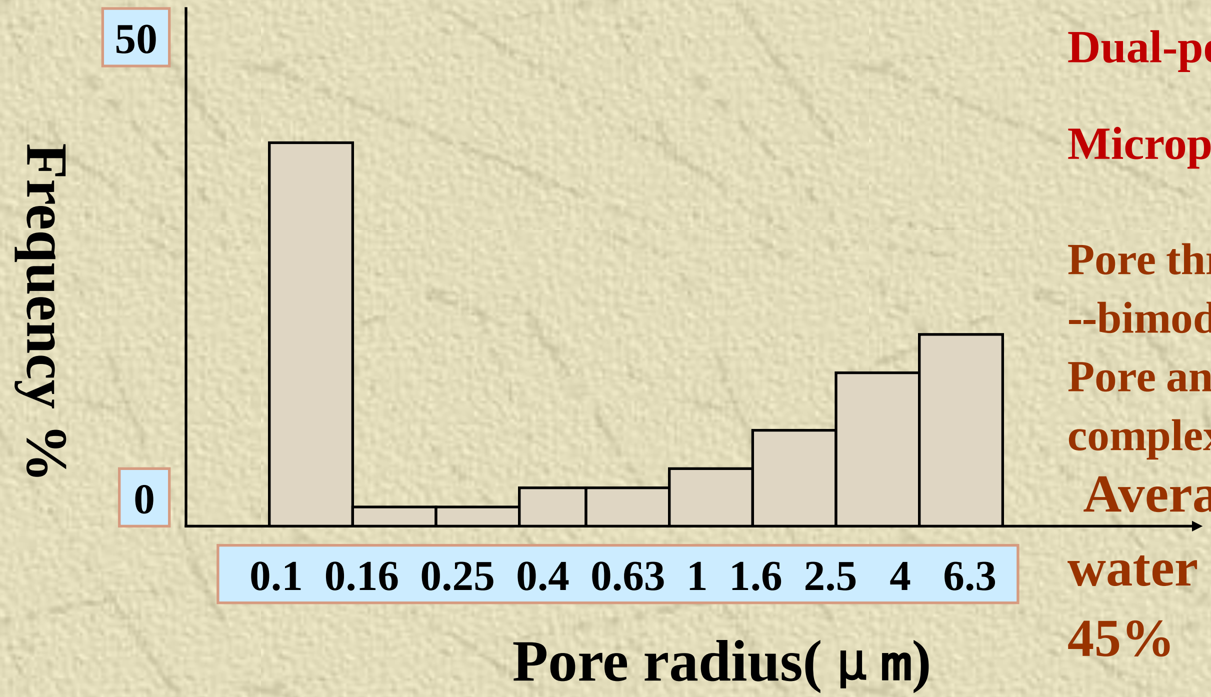
3. Complex pore structure, Narrow pore throat,

   more micropore, high displacement pressure, low K

4. Wettability rock

5. Thin Alternating layers (sand and shale)

Tuha basin low resistivity reservoir



Dual-pore structure

Micropore>30%

Pore throat distribution----bimodal distribution, Pore and throat structure complex,

Average irreducible water saturation 45%

A Case Study for Porosity Distribution of Low Resistivity Reservoir

I. Low Resistivity Reservoir Features

1. Fine grain size， specific surface large， strong absorption ability, high irreducible water content；

   Membrane occluded water----related to adsorption
   Capillary occluded water----related to wettability and capillarity

2. Clay content high， additional conductibility

3. Complex pore structure, Narrow pore throat,

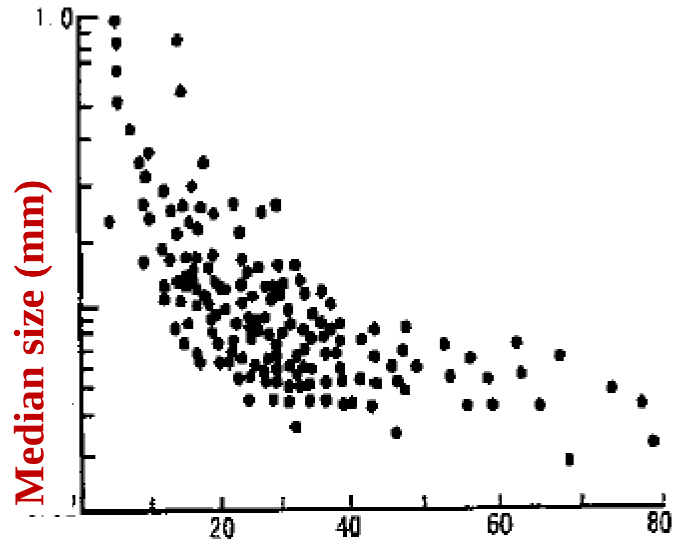
   more micropore, high displacement pressure, low K

4. Wettability rock

5. Thin Alternating layers (sand and shale)

II. Low resistivity reservoir genesis

1. Fine grain size is one of the important factors that resulting in low resistivity



Irreducible water saturation(%)

The relationship between median size and Irreducible water saturation

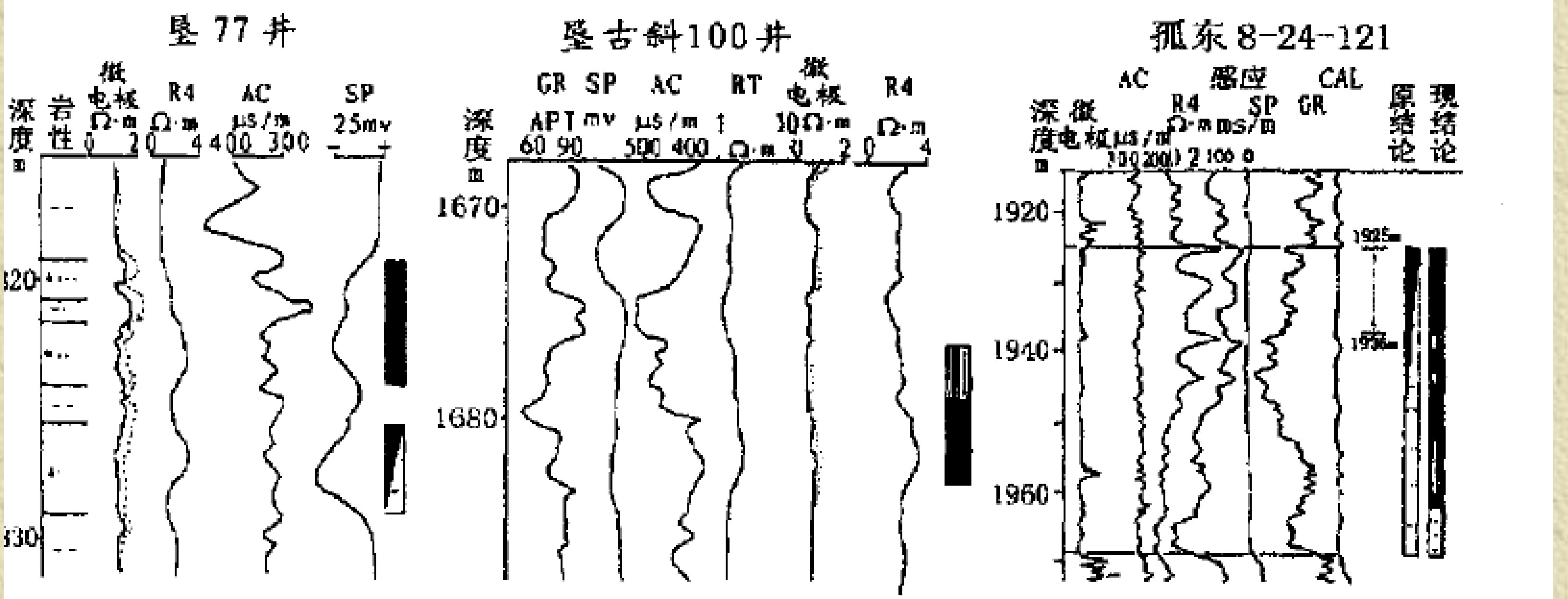
Tuha basin low resistivity hydrocarbon reservoir

- ✶Fine grain size,
- ✶siltstone 23.5%,
- ✶fine sand 52%

The finer the grain, the stronger absorption ability, the higher irreducible water saturation

II. Low resistivity reservoir genesis

2.Enhanced shale content→low-resistivity oil zone

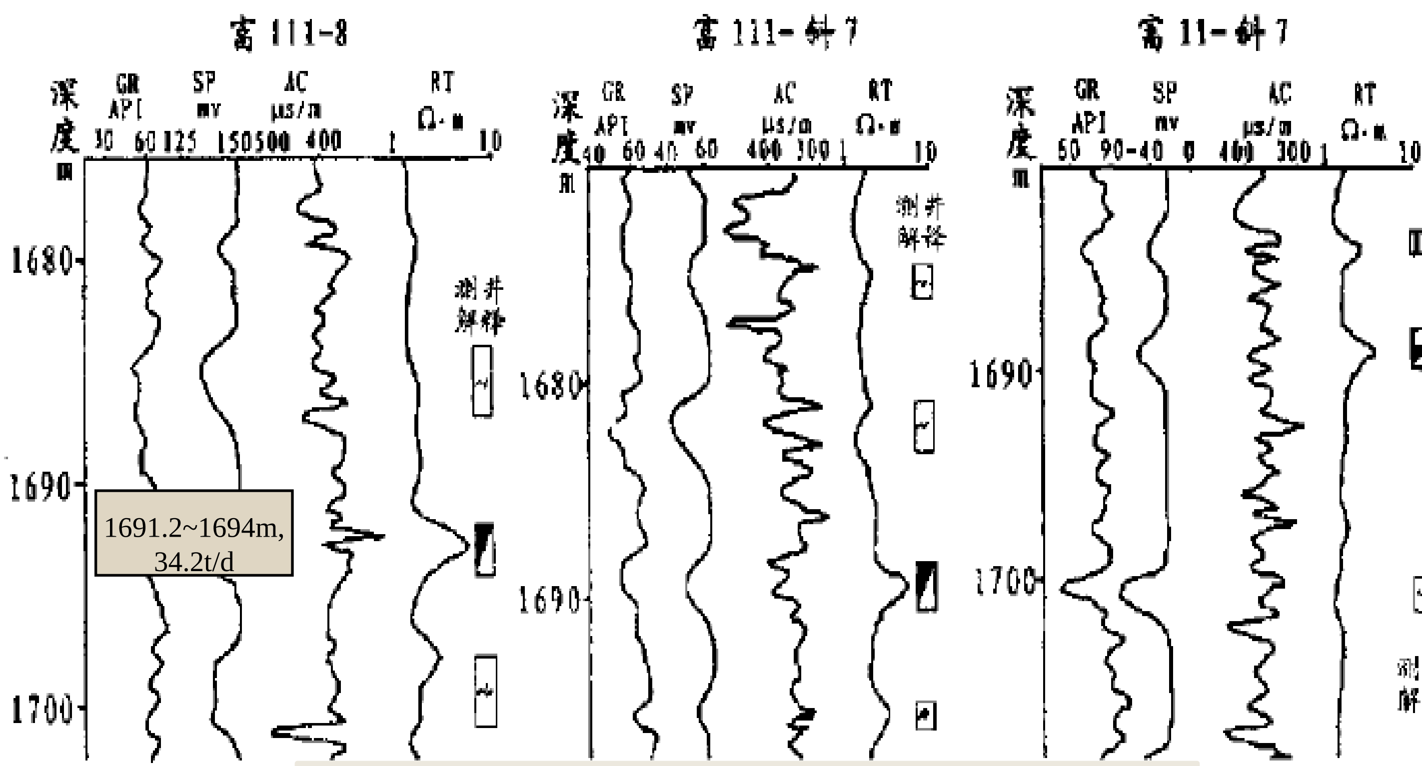


Well logging curve (Shengli Oil field)

- Shale content> 20%→42.7%, shale content increase
- R<4 Ω·m

II. Low resistivity reservoir genesis

3. Thin sand and shale alternating layers



Well logging curve (Shengli Oil field)

Zhanhua Depression

Thin sand bed with mud

Flood plain deposit

Siltstone, fine sandstone

Sandstone thickness≈2m

Low resistivity reservoir

4~5.5Ω·m

Interpreted as

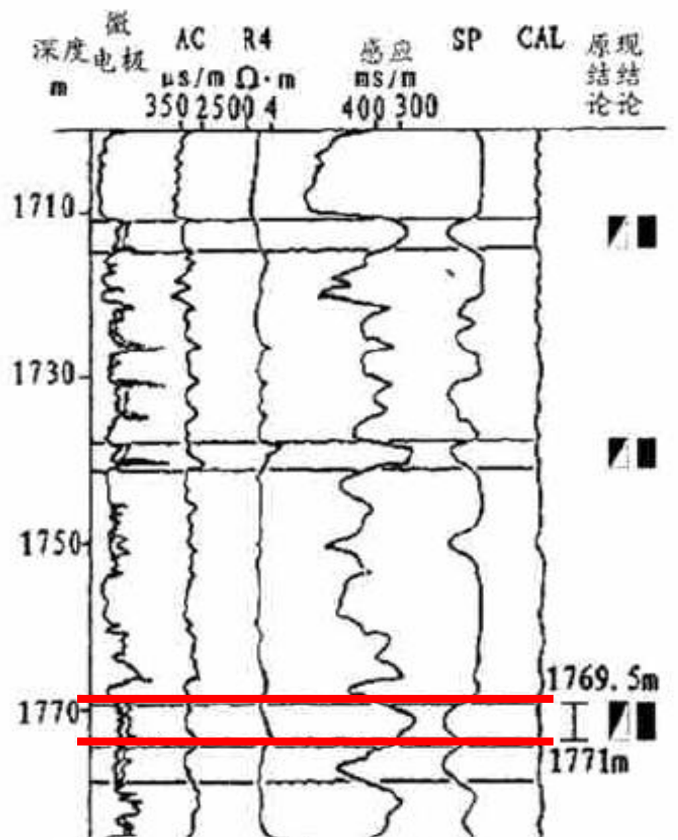
oil/water reservoir

Well test result:

Although the thickness of oil layer is thin and the resistivity is low, commercial oil and gas flow is found through well test

II. Low resistivity reservoir genesis

4. High salinity formation water



Well logging curve

High salinity formation water

⬇

Conductive medium

⬇

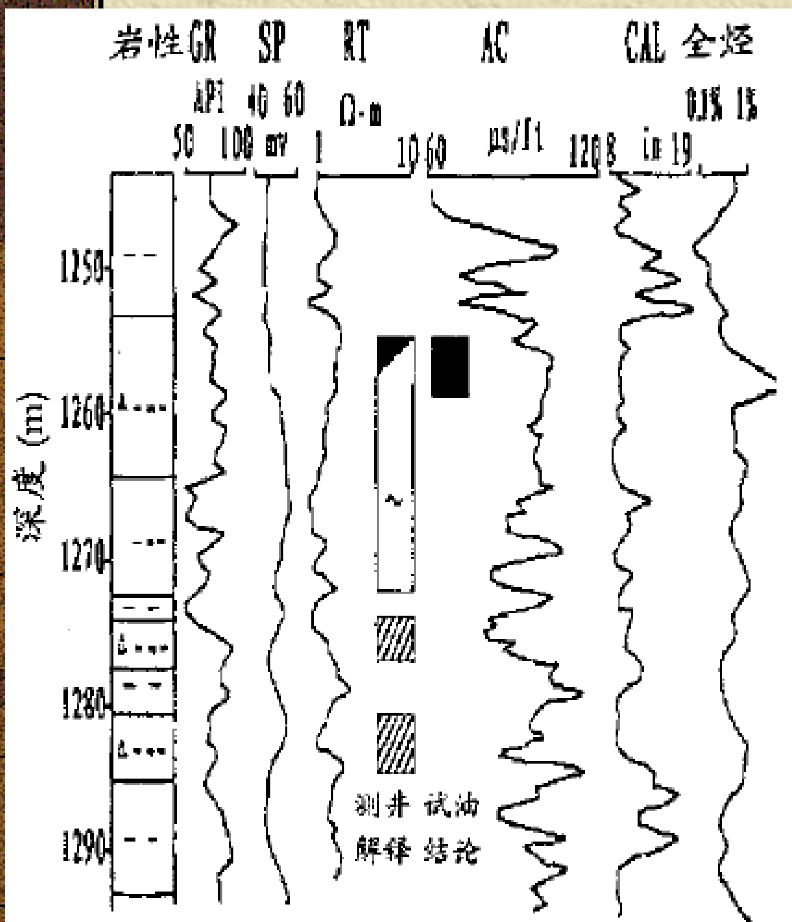
Low resistivity oil reservoir

The formation water mineralization of the Dongying formation in Gudong oilfield is high, total salinity is up to 20400~27000mg/L。

The R4.0=3.8Ω·m in the GD7-22-181 well at the depth of 1769.5 ~1771.0m. It was interpreted to oil/water reservoir, but high hydrocarbon flow (44.1t/d) was achieved after perforation

II. Low resistivity reservoir genesis

5. Mud invasion



Well logging curve

When mud salinity is much greater than formation water salinity, the mud invasion will result in the failure to measure the true resistivity. Sea water mud is used in offshore and coastal waters drilling in Guhua sag. Sea water salinity is 30000- 40000mg/L,if treating chemical is added, mud salinity can be over 80000 mg/L. For oil zone with salinity of 3000 ~ 6000mg/L, its contrast can be 10~20 times. After a week when sea water mud invaded in oil zone with high porosity and permeability, LLd decreased to 1/3~1/2 of oil zone resistivity, mud invasion make oil zone resistivity decrease, log interpretation indicate high water saturation, causing low or false oil zone interpretation. Well KD102 uses water mud. In 1253-1259m of upper Guantao formation, mud density is 1.15 mud resistivity is 0.2Ω·m. LLd only 1.8Ω·m, and log interpretation is oil-water layer. Re-examination showed oil patch in sample log, and in 1255.0m sidewall coring is oil patch siltstone;Gas detection in 1254~1255m increased from 0.16% to 8.3%, methane from 0.02% to 1.38%. Well history showed, there are 14 days between drilled to log in this section That is sea water mud invaded for 14 days. So long invasion of sea water mud is the main reason for low resistivity. In sum, this section should be oil zone. Oil testing in 1253.2~1258.2m, 31.7t oil production per day, without water 。

II.Low resistivity reservoir genesis

1. Grain size;
2. Shale content
3. Thin sand and shale alternating layers
4. High salinity formation water

} Geological genesis

5. Mud invasion — drilling genesis

III. Identification of Low Resistivity Hydrocarbon Reservoirs

1. Movable water method
2. Sw-Swi Fast-looking

III. Identification of Low Resistivity Hydrocarbon Reservoirs

1. Movable water method

Krw--water relative permeability
Kro—oil relative permeability
Sw---water saturation
Swi--- irreducible water saturation
Sor---residual oil saturation

$$Krw = \left(\frac{Sw - Swi}{1 - Swi} \right)^{m}$$

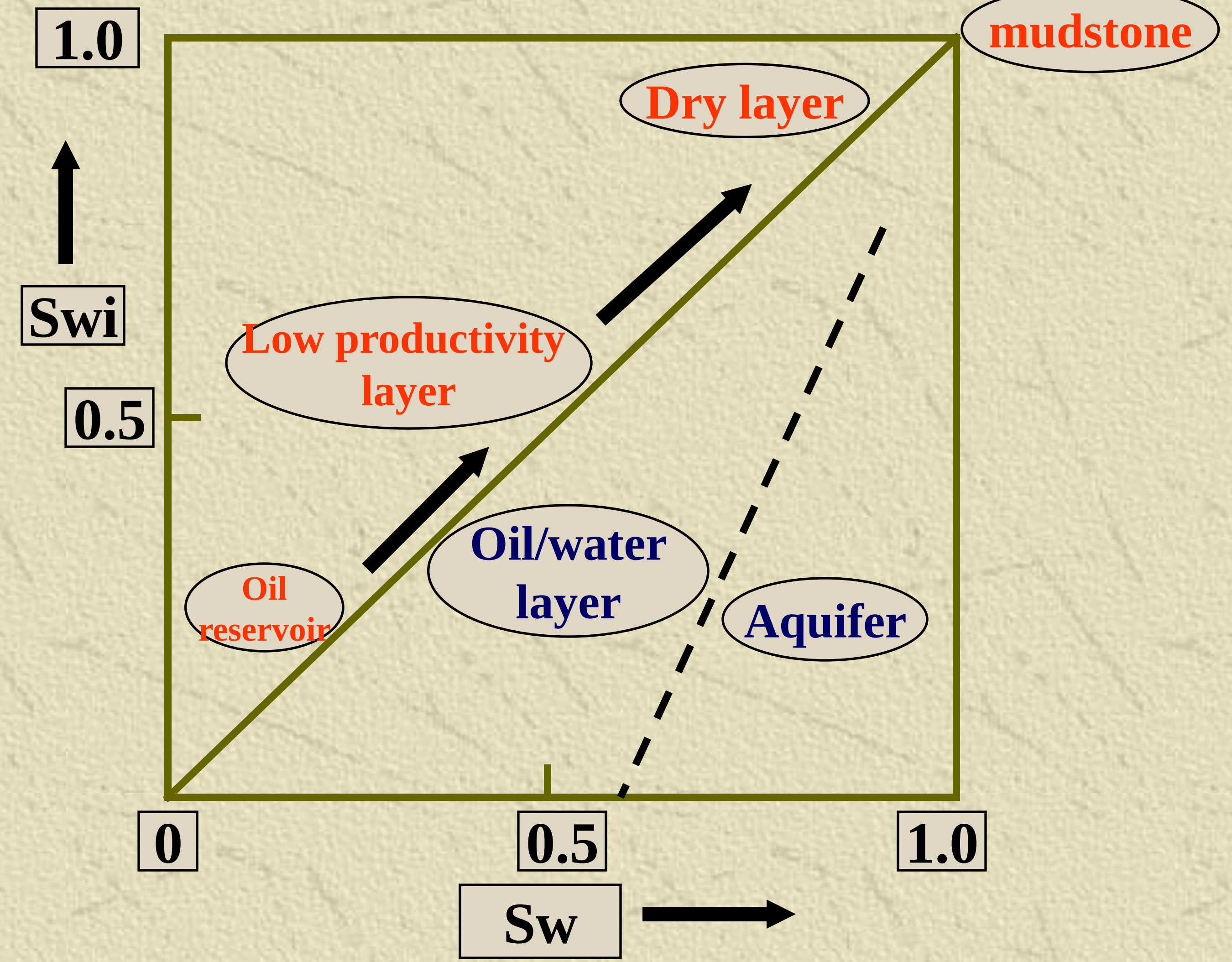
$$Kro = \left[1 - \left(\frac{Sw - Swi}{1 - Sor - Swi} \right) \right]^{n} \bullet \left[1 - \left(\frac{Sw - Swi}{1 - Sor - Swi} \right)^{j} \right]$$

Water bed: Sw→1, Swi→0, Krw→1,Kro→0,Swm>0
Oil bed: Sw=Swi, Swm=0, Krw=0, Kro=1
Oil-water layer: Sw>Swi, 0<Kro<1, 0<Krw<1

III. Identification of Low Resistivity Hydrocarbon Reservoirs

2. Sw-Swi fast-looking

(1)Sw-Swi Crossplot



1.0
mudstone
Dry layer
Swi
Low productivity layer
0.5
Oil reservoir
Oil/water layer
Aquifer
0
0.5
1.0
Sw

(2)Sw-Swi overlap plotting

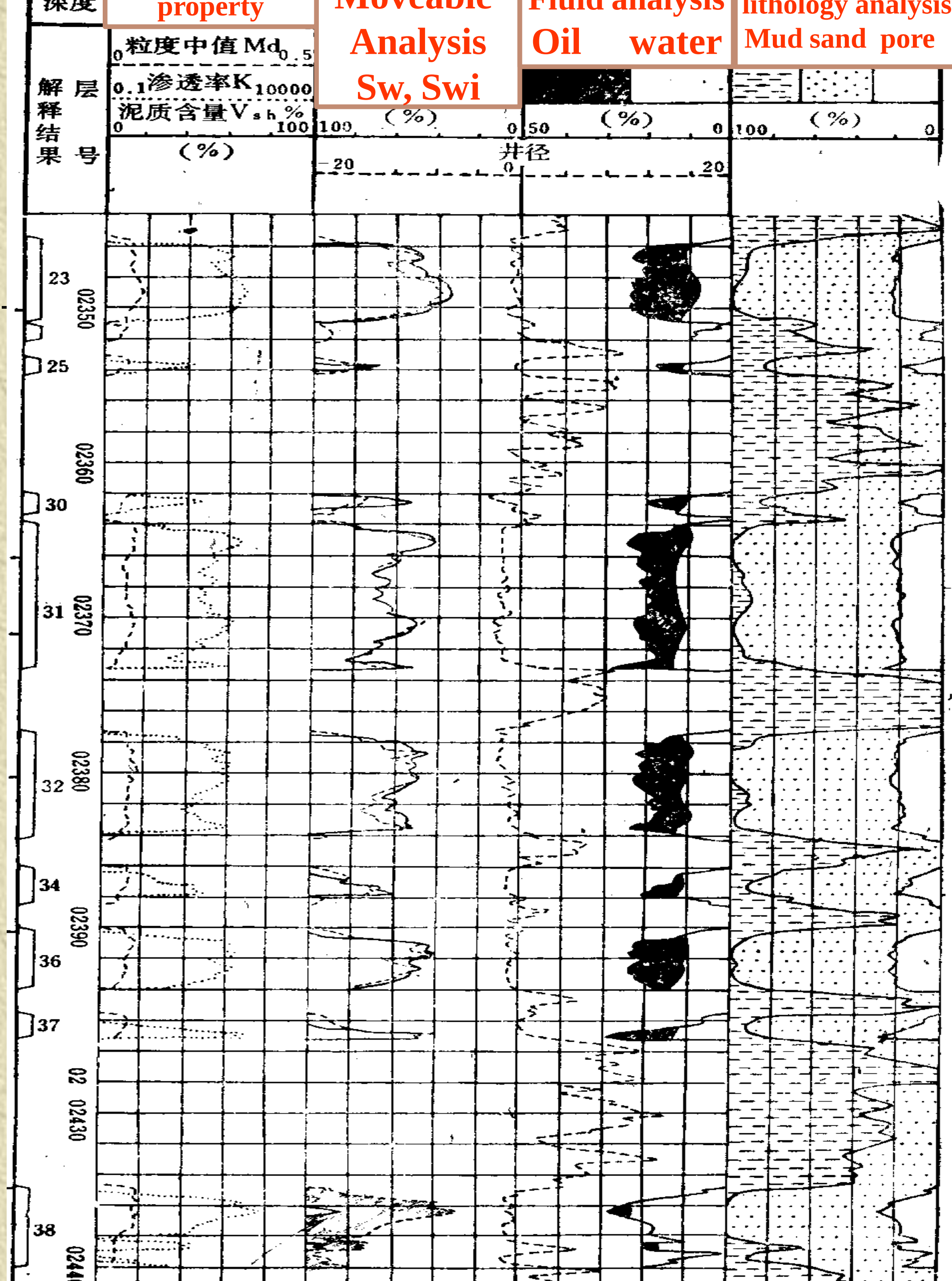
Oil layer: $S_w \approx S_{wi}$, $S_{mos}>0$

Low production layer: $S_{wi} \le 75\%$, $S_o \ge 25\%$

Dry layer: $S_{wi}>75\%$

Oil/water layer: $S_w>S_{wi}$, $S_{wm}>0$

Aquifer: $S_w \gg S_{wi}$, $S_{wm}>0$



Sw=Swi, oil bed

High Sw, Swi, dry layer

Sw>>Swi, Aquifer

Chapter 2 Identification of reservoirs and reservoir fluids

What? Why? How?

Section 1 Main Well Logging Methods

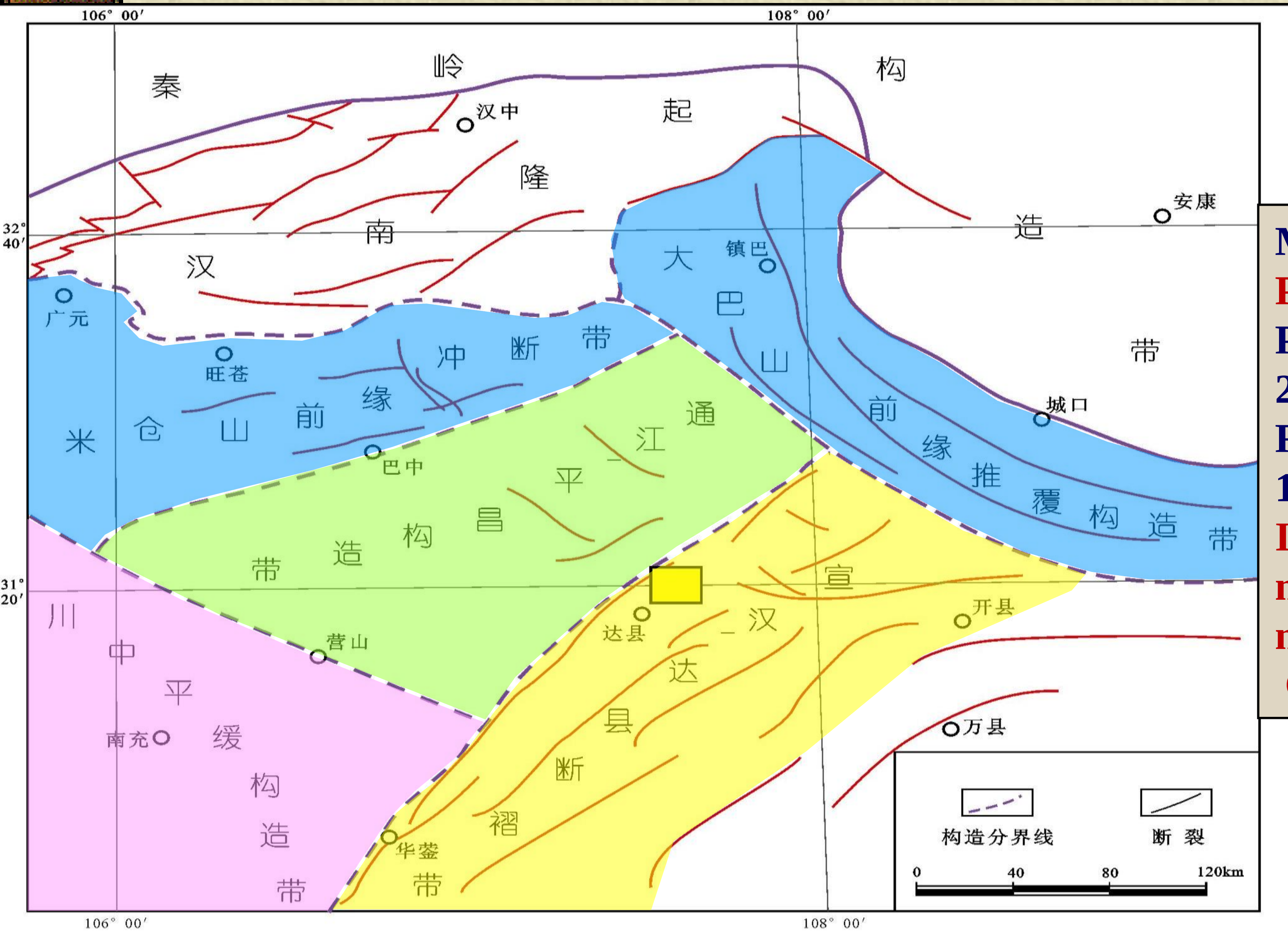
Section 2 Identification of Hydrocarbon Reservoirs in Clastic Sections

Section 3 Identification of hydrocarbon reservoirs in Gypsum and Salt Rock Sections

Section 4 Identification of Low Resistivity Hydrocarbon Reservoirs

Section 5 Identification of Fractured Hydrocarbon Reservoir in Carbonate Sections

Section 5 Identification of Fractured hydrocarbon reservoirs in carbonate sections



Marine carbonate
Puguang gas field
Proved reserves 2510million cubic,
Recoverable reserves 1183million cubic
It is the largest and most abundant large marine gas field in China

The northeast of Sichuan basin (Southern Company，2005)

Section 5 Identification of Fractured hydrocarbon reservoirs in Carbonate Sections

I. Carbonate Reservoir types

II. Identification Fracture Reservoir

III. Identification of Fractured Hydrocarbon Reservoirs

I. Carbonate Reservoir Types

1. Pore

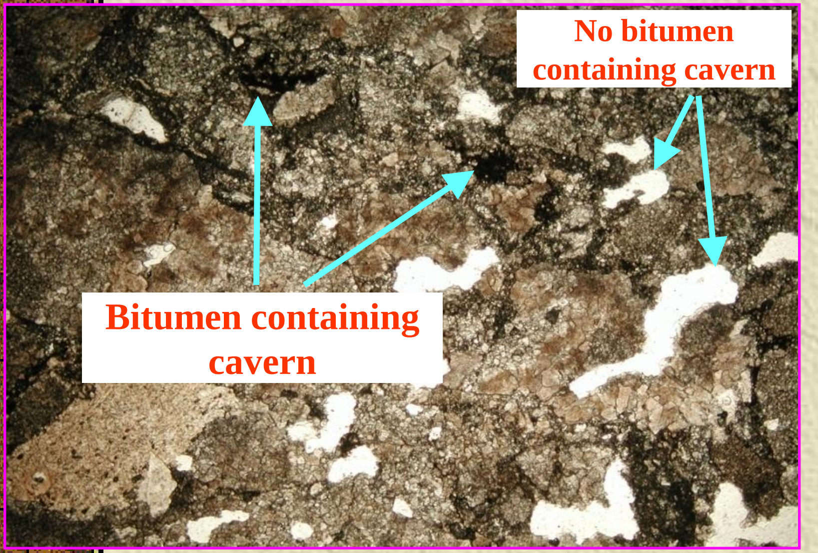
Primary pore （Intergranular pore, Intercrystalline pore, Intragranular pore）

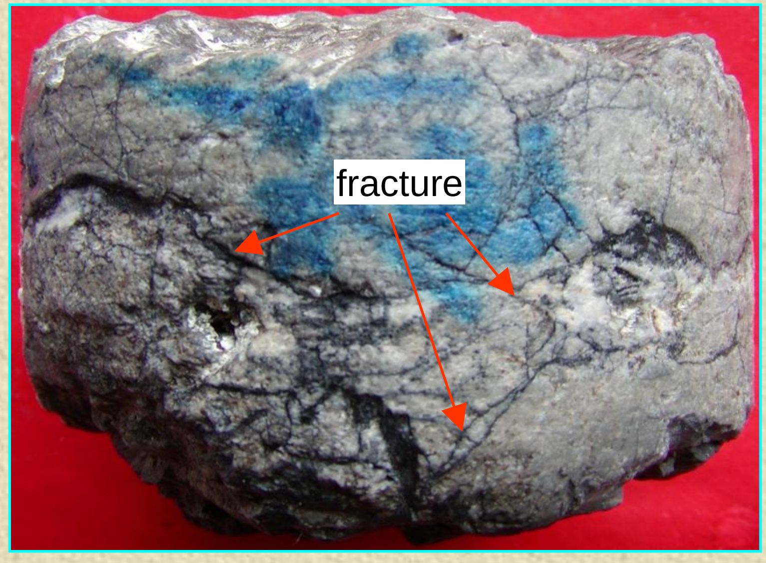
2. Cavern

Secondary change----solution void and cavern

3. Fracture and metric-pore

Fracture system
Metric-pore system

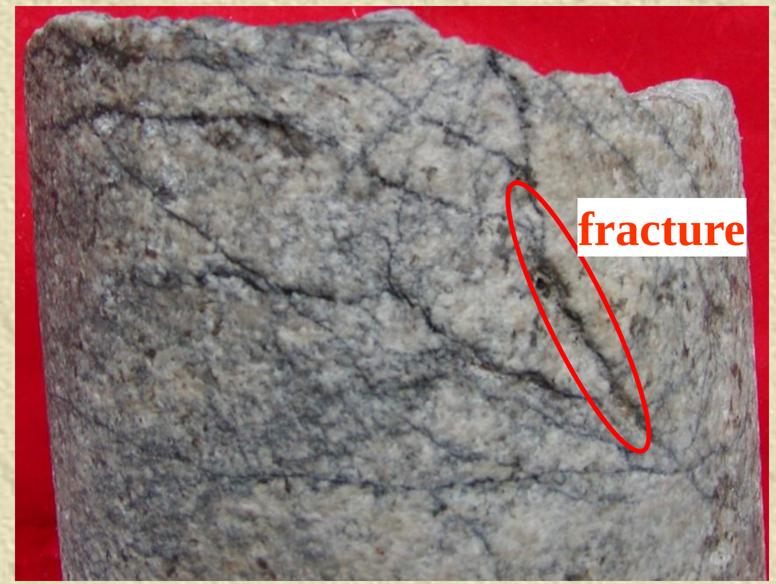




Solution cavity:
corrode along the bedding plane

Puguang2, 4958m,T_1f_2,
Relic oolith dolomite

Oolith mold
develop alone the fracture



Puguang2， 5008m, T_1f_2,
Crystallization oolith dolomite

II. Identification Carbonate Fracture Reservoir

(I) Geological logging features

1. Decreasing drilling time when drilling into a cavity or fracture;

2. High Secondary calcite in cuttings;

3. Well blowout and lost circulation during drilling;

4. Core logging: Cavern and fracture developed

5. Carbonate low Φ , K; $\Phi<2\%$, $K<1md$

6. Strong heterogeneity

II. Identification Carbonate Fracture Reservoir

（II）Fracture Reservoir well logging features

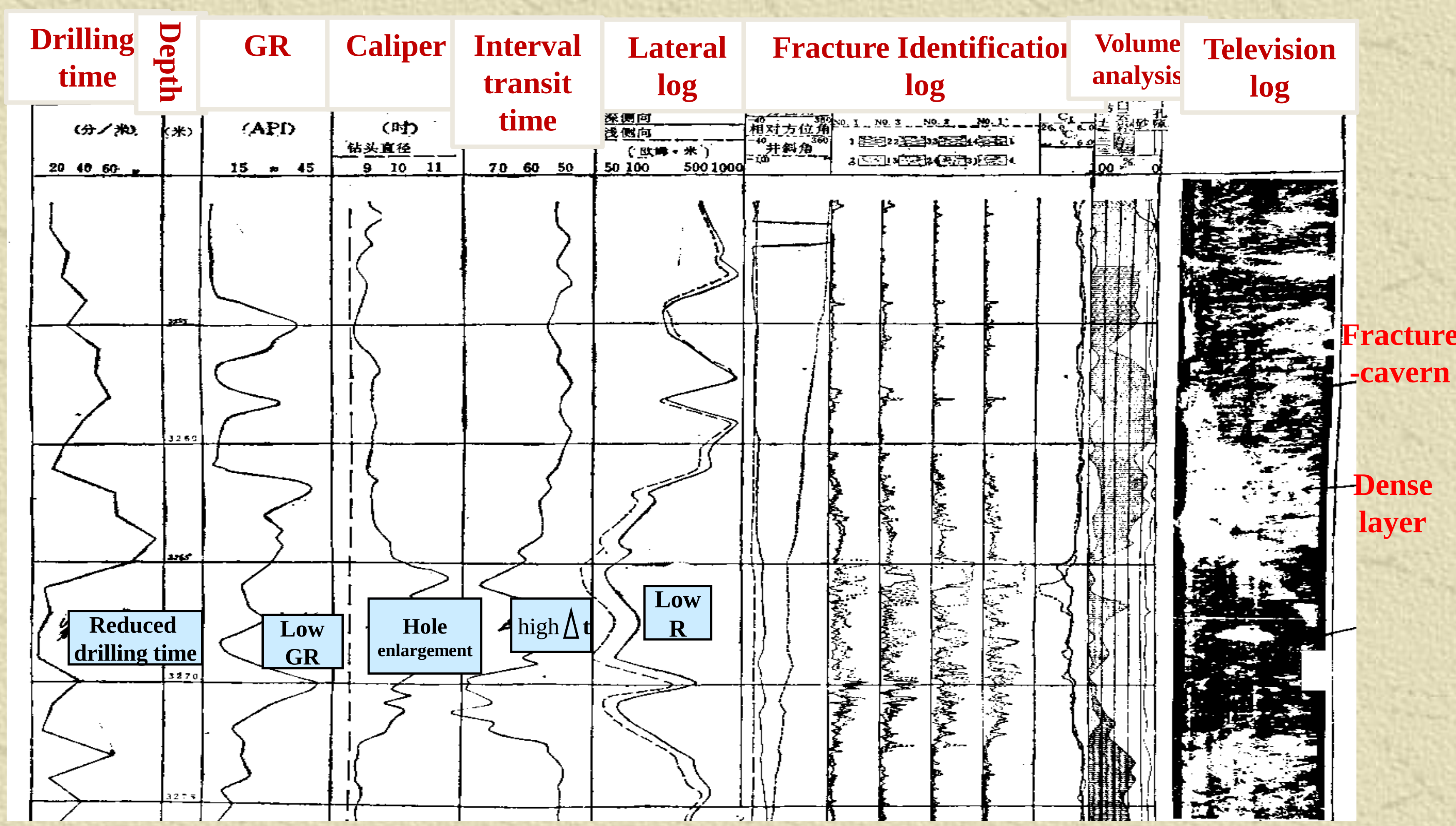
Conventional well logging methods
Special well logging methods

II. Identification reservoir

(II) Fracture Reservoir well logging features

1.Conventional well logging methods

Carbonate	High resistivity, neutron gamma ray, low neutron porosity Low natural gamma, interval transit time
Fracture — Three low	resistivity, neutron, natural gamma
Fracture — Two high	interval transit time, neutron porosity
Fracture — One low	density


Drilling time
Depth
GR
Caliper
Interval transit time
Lateral log
Fracture Identification log
Volume analysis
Television log
(分/米)
(米)
(API)
(吋)
钻头直径
深侧向
浅侧向
20 40 60
15 45
9 10 11
70 60 50
50 100 500 1000
Fracture -cavern
Dense layer
Reduced drilling time
Low GR
Hole enlargement
high Δt
Low R

II.Identification reservoir

(II)Fractured reservoir well logging

2. Special logging methods

(1) Fracture identification log

(2) LLD,LLS-Rxo

(3) Downhole television logging

(4) Litho-density log

(5) Sibilation log

(II)Fractured Reservoir Well Logging

2. Special logging methods

(1)FIL Fracture identification log

4 microconductivity curves

2 caliper curves

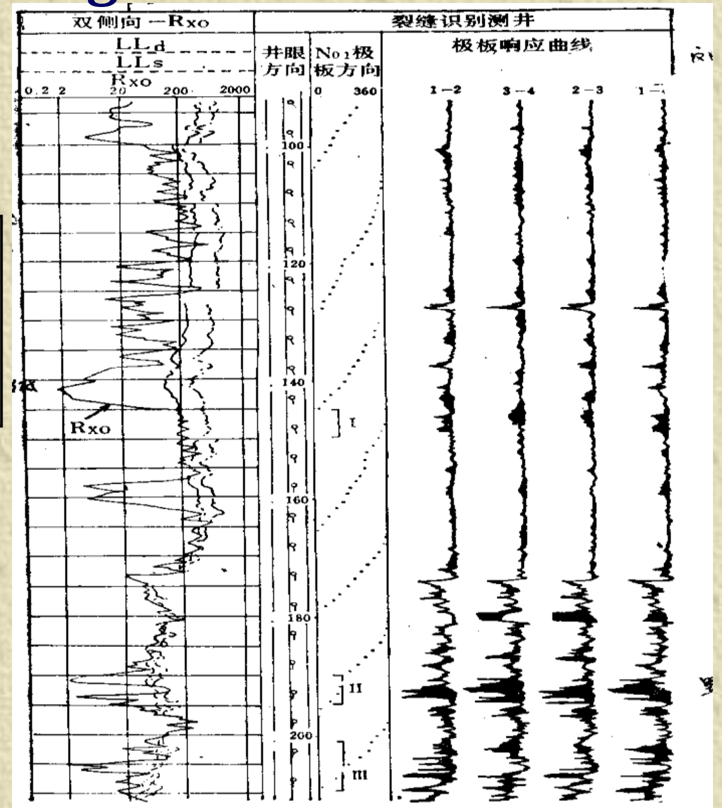


图 2—23 用双侧向—Rxo与裂缝识别测井探测裂缝

（据 Suau and Gartner，1980）

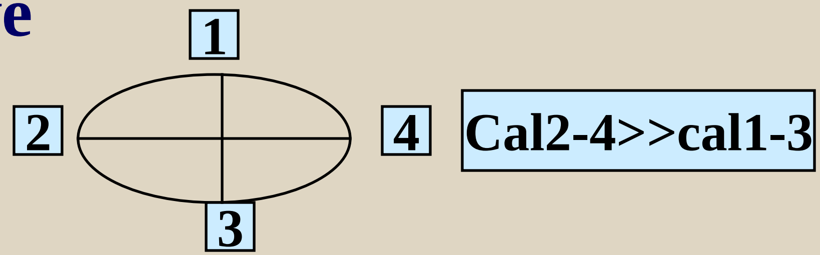
(II)Fractured Reservoir Well Logging

2. Special logging methods

(1)FIL Fracture identification log

4 microconductivity curves

2 caliper curve



Formation with value of dual caliper curve bigger than bit diameter is mudstone and loose cavy. Due to empty and sidewall collapse caused by cave and fracture, dual caliper curve value in certain direction is bigger than bit diameter, in another direction equals or less than bit diameter, always indicating high-angle fracture(including vertical fracture.

(II) Fractured Reservoir Well Logging

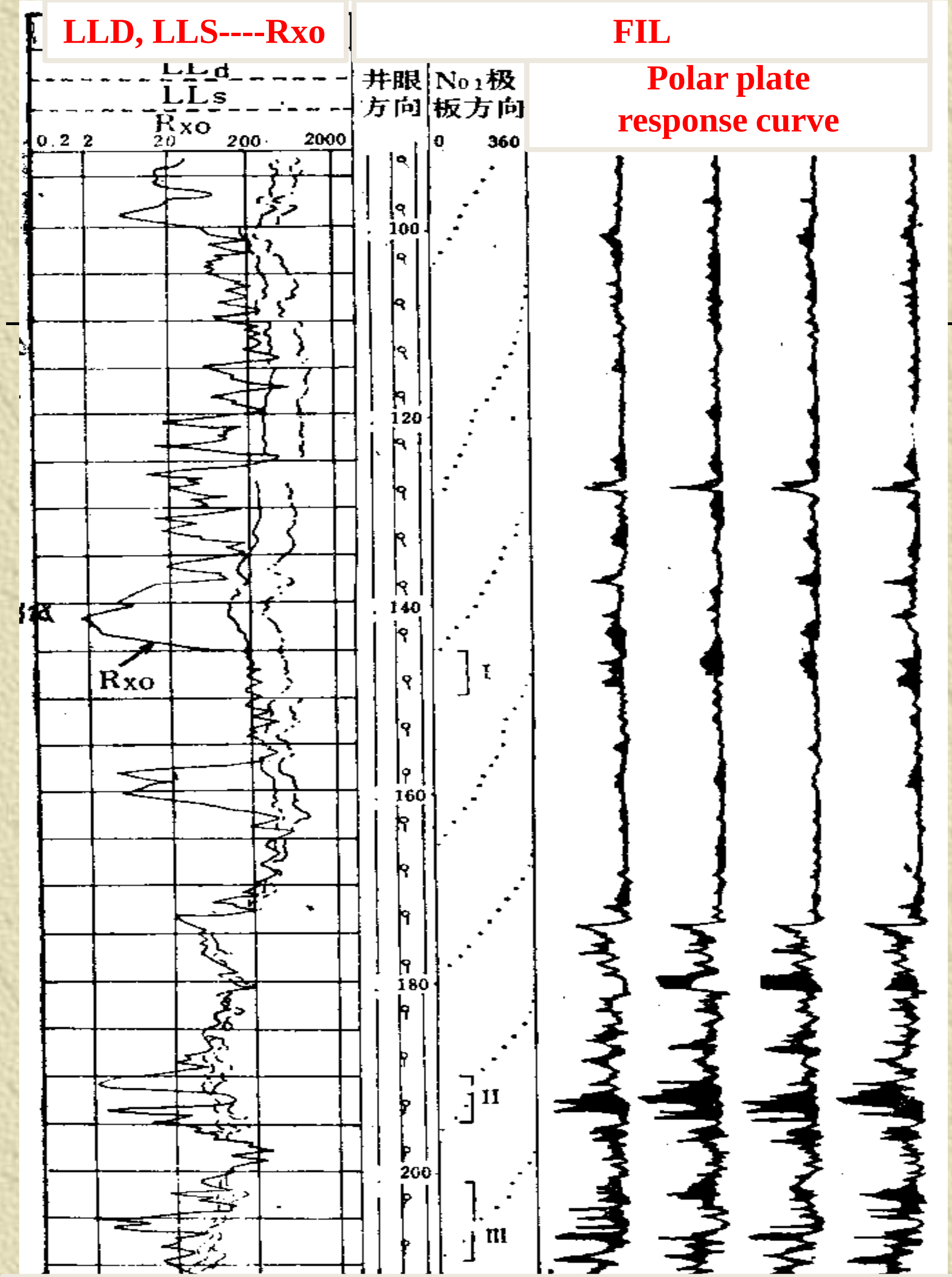
2. Special logging methods

(2) LLD, LLS----Rxo

deep investigation laterolog---- LLD

shallow investigation laterolog---- LLS

Resistivity of flushed zone---Rxo

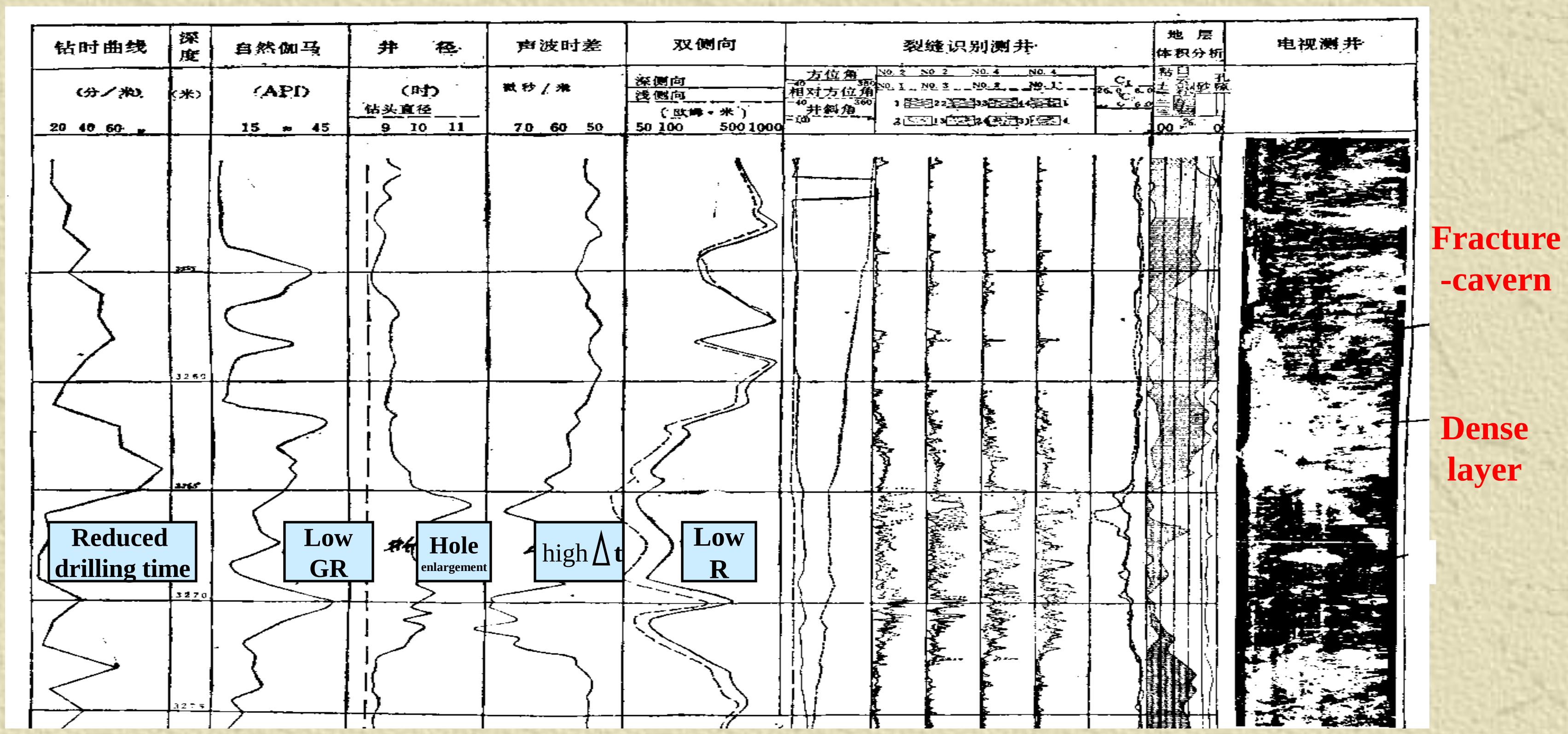


LLD, LLS—Rxo and FIL identifying Fracture

(II)Fractured Reservoir Well Logging

2. Special logging methods

(3) Downhole television logging

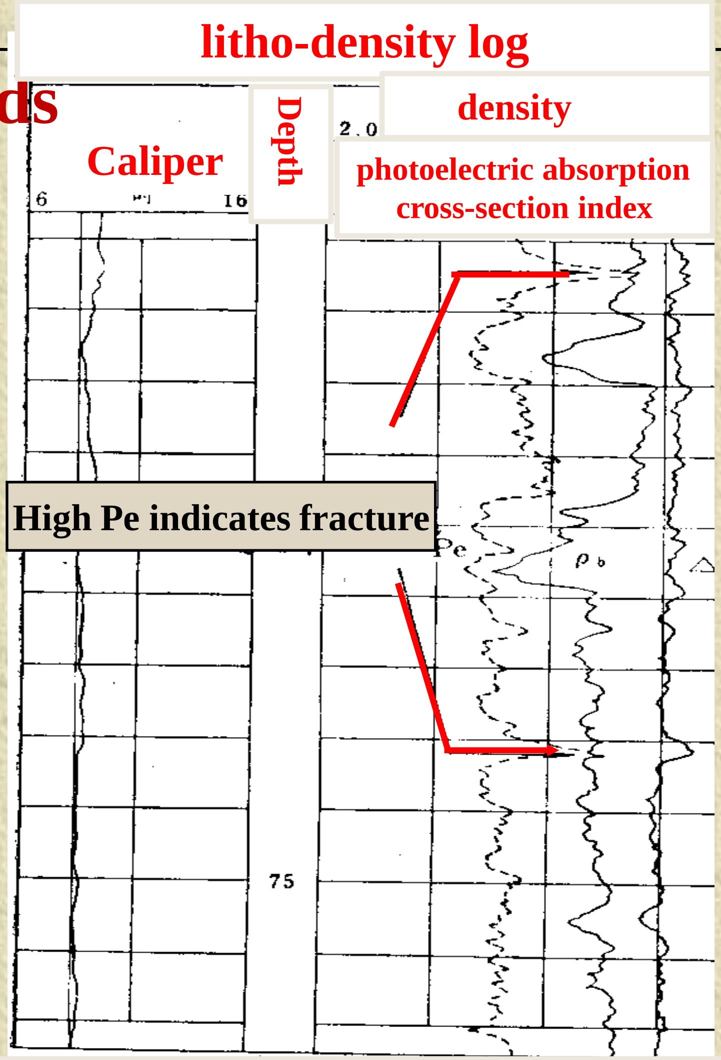


(II)Fractured Reservoir Well Logging

2. Special logging methods

(4)litho-density log

Pe---photoelectric absorption cross-section index

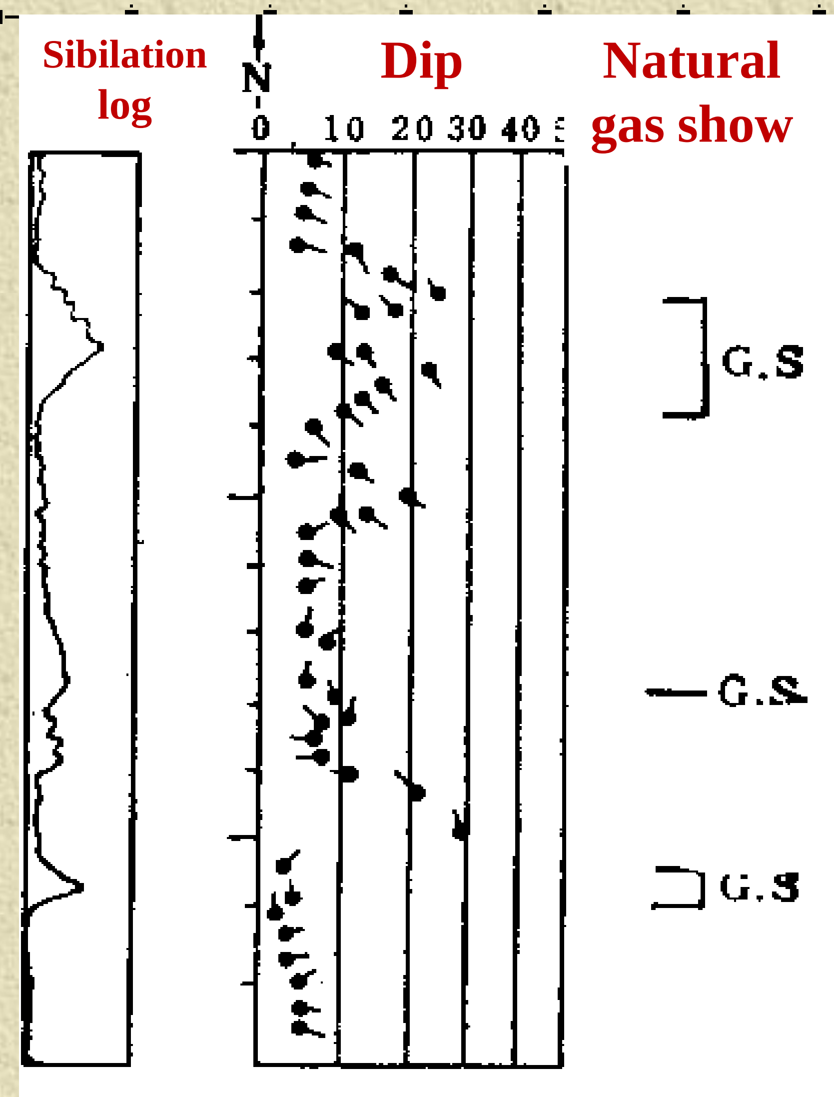


Fracture on litho-density log curve

(II)Fractured Reservoir Well Logging

2. Special logging methods

(5)Sibilation log



III. Identification of Fractured Hydrocarbon Reservoir

1. Rt, Rxo overlay method

Oil-bearing formation--Decreased resistance invasion, $Rt>Rxo$

Water layer----Increased resistance invasion, $Rt<Rxo$

Tight formation Rt, Rxo overlay, high resistivity, low GR

Shale ---- Rt, Rxo overlay low resistivity, high GR

III. Identification of Fractured Hydrocarbon Reservoir

2. ϕ_T, ϕ_w Method

ϕ_T----NGR
ϕ_w ----LLD

$\phi_T = \phi_w$ ---- Water Layer
$\phi_T > \phi_w$ ---- Oil-bearing Reservoir
$\Phi_w > \phi_T$ ---- Fracture Hydrocarbon Reservoir

Comprehensive Questions:

1. What are the main well logging methods?
2. Sand will have ____ (high/low) resistivity comparing with the shale?
3. Oil have ____ (high/low) resistivity comparing with the water?
4. What’s difference between sand and shale SP curve?
5. Were micrologs were developed to locate and define thin permeable beds?
6. What is one of the major use of the dipmeter?
7. Are the high gamma ray counts related to shale? How about low gamma ray counts?
8. Explain the features of clastic profile.
9. How to identify the clastic reservoirs with well logging curves?
10. How to indenty the oil bed and water bed with movable water method?
11. Explain the features of gypsum and salt rock sections.
12. Summary the low resistivity reservoir features.
13. Analysis low resistivity reservoir genesis.
14. Analysis Sw-Swi Crossplot and overlap plotting.
15. Carbonate Reservoir types.
16. Carbonate fracture reservoir geological logging features.
17. Carbonate conventional well logging features.
18. Carbonate fracture reservoir conventional well logging features
19. How to use FIL identifying fracture?

1. Summary main well type
2. What is the difference purpose between evaluation well and appraisal?
3. Explain generalized drilling geology
4. Analysis advantages of deviated and multiple well
5. What are the purposes and main methods of geological logging?
6. Analysis the cutting logging features.
7. Explain delay time. How to get delay time?
8. Coring type and principle
9. Explain mud circulation

Explain drilling fluid properties.

What are the basic functions of drilling fluid during drilling?

Explain the application of drilling –time curve

What are the advantages of formation Testing?

Explain the pressure card

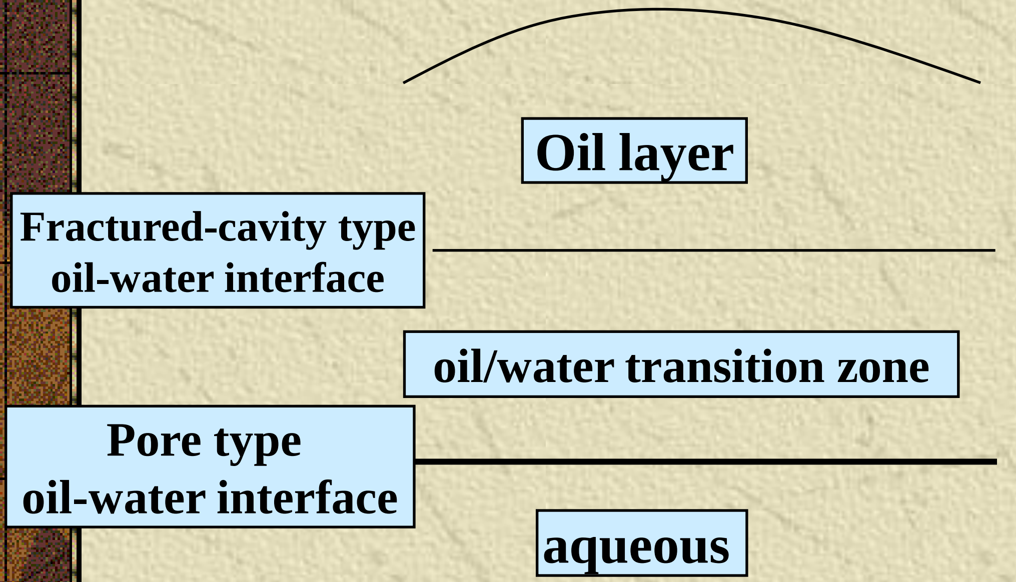
Explain the Casing scheme

The purpose of well cementing

Well completion objective

三. Fractured-cavity type oil/water layer assessment

3.Reservoir identification using oil-water interface



(1) Fractured-cavity reservoir

A. $\Phi_N \geq 2\phi_w$

B. $\Phi_w \leq 3.8\text{-}4.6\%$

C. $\phi_w = \phi_{wi}$

D. $\phi_w < 4\%$ produce pure oil

(2) Fracture or cavity zone

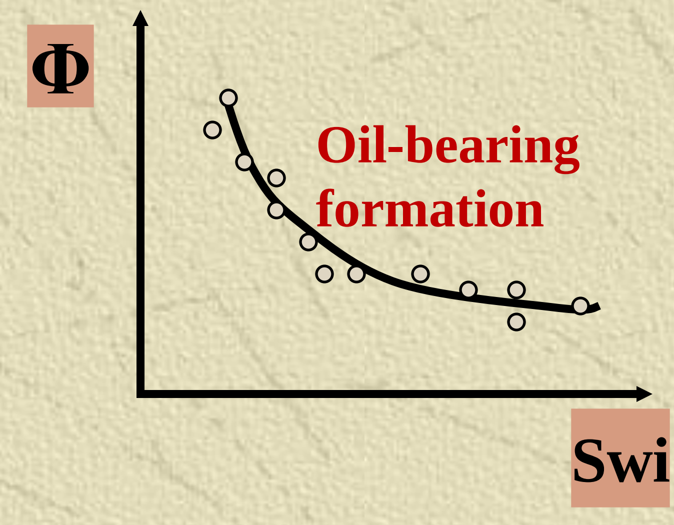
$\varphi_W > \varphi_{NG}$

$$\varphi_W = \sqrt[m]{\frac{Rw}{Rt}}$$

$$\sqrt[2]{\frac{Rw}{Rt}} > \sqrt[1.2]{\frac{Rw}{Rt}}$$

三. Fractured-cavity type oil/water layer assessment

4.Swi- Φ Cross plot



Φ* Swi=C(constant)