Saturation Monitoring, Sweep Evaluation and Identification of Bypassed Oil in a Heterogeneous Carbonate Reservoir, Raudhatain Field, North Kuwait*

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Abstract

The Mauddud Formation in North Kuwait is a giant carbonate reservoir undergoing pattern sea water flooding for the past 9 years in absence of aquifer support. The reservoir has a 48 year production history with reservoir pressure depleted below bubble point with only 4% of inplace oil produced from few wells of high productivity index. In addition to extreme reservoir heterogeneity, there is areal and vertical variation in oil properties. Flood water break-through in producers has varied from 6 months to 3 years. The reservoir pressure has shown uneven increase and is close to initial pressure at structurally favorable areas. In order to optimize production and sweep in the water flood, it is important to identify the layers of premature water breakthrough and monitor subsequent saturation changes.

Pulsed Neutron Decay logs are the conventional logging tools used for analyzing high saline formation water encroachments in Burgan and Zubair reservoirs of the field. With less saline sea water injection, these logs are not sensitive enough to evaluate the encroachments as neutron capture properties of injected water and oil are closer. Mixed formation and injected water pose further challenges in Mauddud Reservoir, but we have found that Pulsed Neutron Scatter logs (C/O) logs in combination with capture logs are useful to monitor water movements.

We have carried out an integrated study using C/O log water saturation from 19 wells with production logs, well performance, core data and structure for evaluating sweep, saturation monitoring and thief zone identification. The C/O logs have been quality checked and optimized for different vendors, available tool sizes, number of logging passes, oil/water contribution from PLT, actual volume of produced oil/water and effect of oil gravity. The integrated approach enabled identifying thief zones in perforated and unperforated layers in wells and mapping their areal distribution. Stochastic and deterministic water saturation models biased to petrophysical and structural trends were used to identify swept zones and bypassed oil.

The quantitative results from C/O logs were useful in high porous zones only when an integrated approach eliminated the effects of hold up, filtrate invasion, oil quality and Shale volume. However, our results show that the technique is qualitatively useful for water flood monitoring, planning infill wells and in formulating perforation policy to target bypassed zones while avoiding thief zones.

Saturation monitoring, Sweep Evaluation and Identification of Bypassed Oil Using Carbon-Oxygen Logs: Mauddud Reservoir, Raudhatain Field

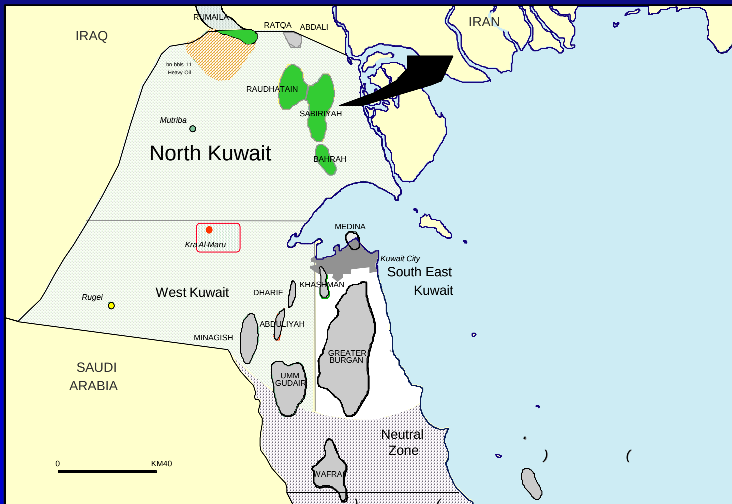
Shaikh A/Azim, Mansoor Ali, Yahya Hassan, Ashok Pathak, Ahmad Mousawi, Krenek Ron and Hamad Al-Ajmi

Outline

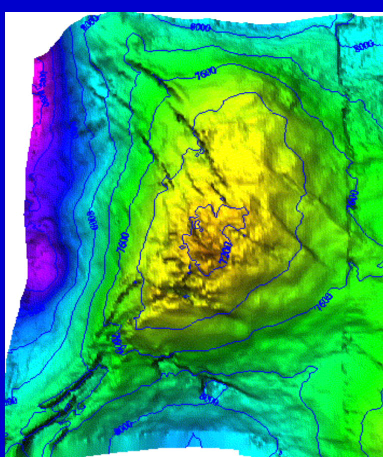
- Mauddud Reservoir in North Kuwait
- Principle of C/O Logging
- Significance of C/O Logging in Mauddud Water flood
- Results of C/O Analysis
- Repeatability of results with different vendors
- Swept and Bypassed oil zones
- Quantitative use of C/O logs
- Sensitivity
- Can we use Sigma in place of C/O?
- Limitations
- Summary and Conclusions

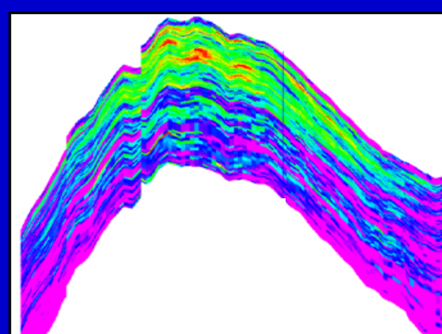
Mauddud Reservoir in North Kuwait

GEOLOGICAL SETTING



Structure



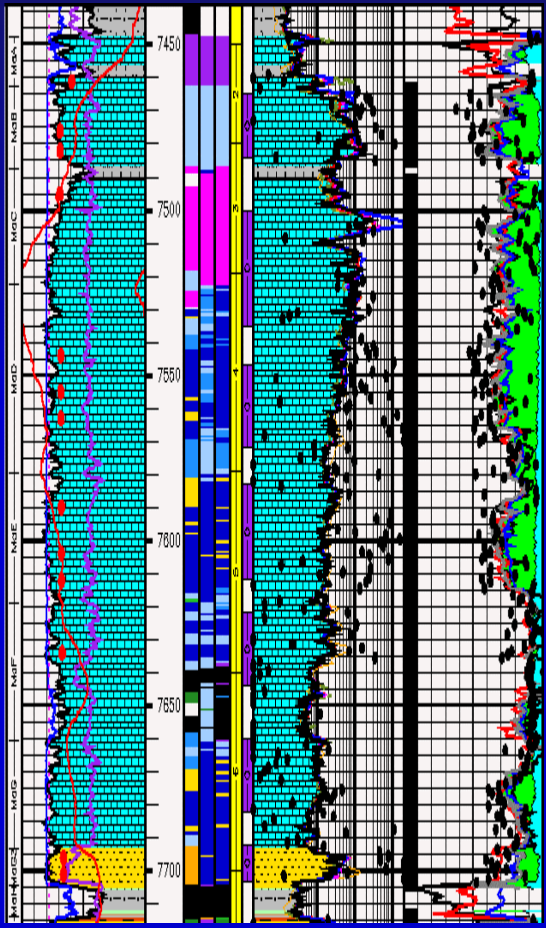


STRATIGRAPHY

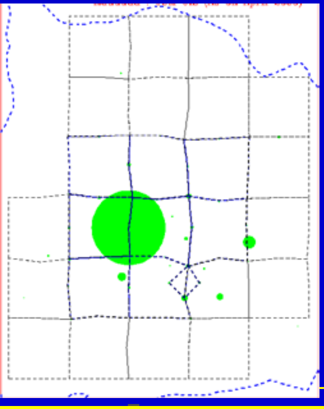
Sub Period	Epoch	Formation	Age
Quarternary	Holocene	Surface	0.01
	Pleistocene	Dibdibba	1.64
Tertiary	Pliocene	Lower Fars	3.4
	Miocene	Ghar	5.2
	Oligocene	Dammam	23.3
	Eocene	Rus	35.4
	Paleocene	Radhuma	56.5
Cretaceous	Maastrichian	Tayarat	65
		Quama	
	Campanian	Harta	74
		Sadi	
	Santon	Khasib	83
	Coniac	Hiatus	86.6
	Turonian		
Upper	Cenomanian	Mishrif	90
		Rumaila	95
Lower		Ahmadi	96
	Albian	Wara	97
MAUDDUD		Mauddud	98
		Burgan	100
			?
		Hiatus	
	Aptian	Shuaiba	112
		Zubair	120
	Barremian		
	Hauterivian		133
		Hiatus	
	Valangian	Ratawi sh & ls	139
	Beriassian	Minagish	140
		Makhul	
Jurassic	Tithonian	Hith	146
		Gothnia	
	Kimmerian	Nahma	152.1
Upper	Oxfordian		154.7
	Callovian		157.1
	Bajocian	Sargelu	161.3
	Bathonian		168.1
Middle	Aalen	Dharuma	172.5
	Toarcian	Marrat	178
	Pliensbachium		187
	Sinemurium		194.5
Lower	Hettangium		200.5
Triassic	Rhaetian	Minjur	208
	Norian		209.5
	Carnian		223.4
	Ladinian	Jilh	225
	Anisian	Sudair	229.5
	Scythian		241.1
Permian	Tartarian	Sudair	245
	Kazanian	Khuff	256.1

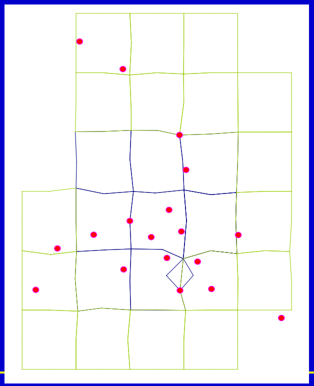
Mauddud Reservoir

- Heterogeneous Reservoir
- Areal & vertical variation in oil quality
- 48 Years of Production
- I-9 spot Sea water injection
  - ❖ Break through 0.5 to 3 years
- Variable Salinity Flood Monitoring
  - ❖ Optimize production and sweep
    - Identify layers of premature water breakthrough and monitor subsequent saturation changes.

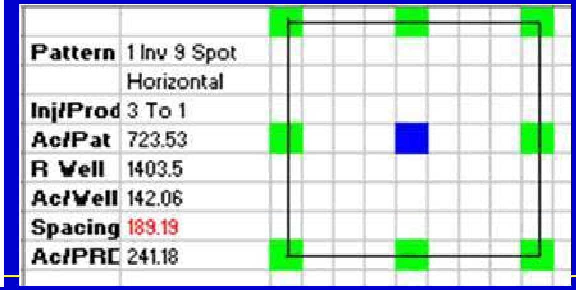


Layering Scheme





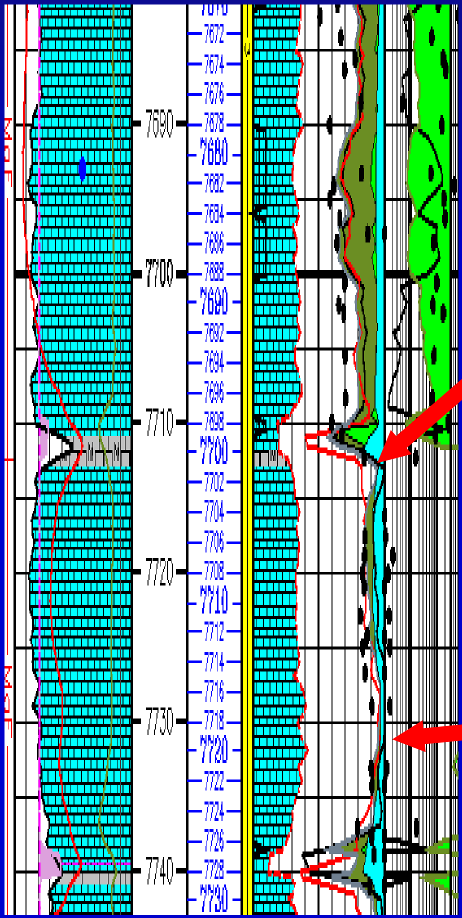
Mauddud: Cumulative offtake

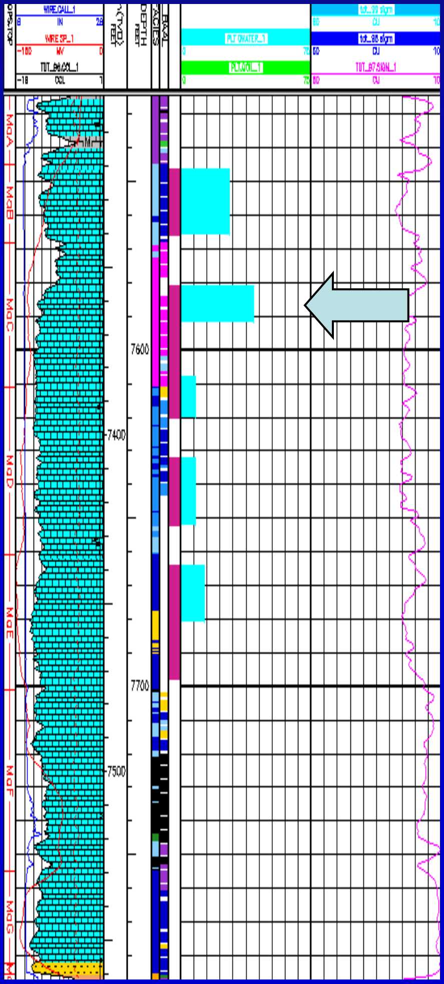


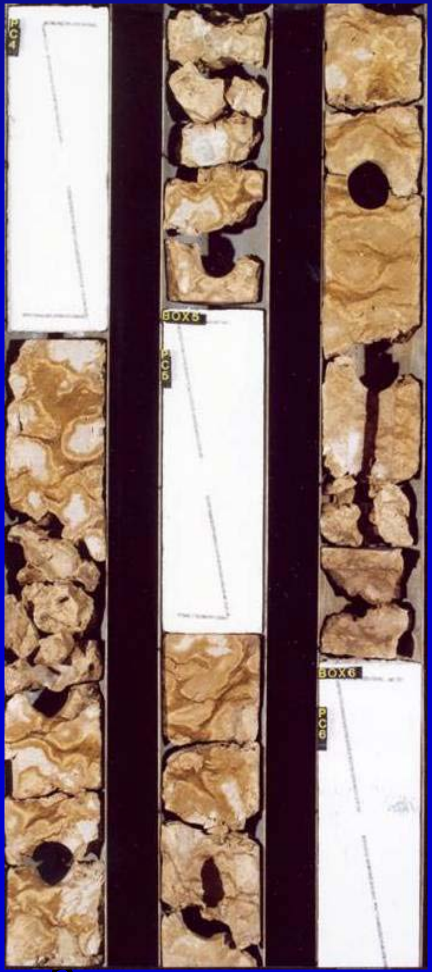
Phased Development

High Perm Features in Mauddud

- Low Porous Zones: Fractured
- High Porous Rubble (Vuggy) Zones

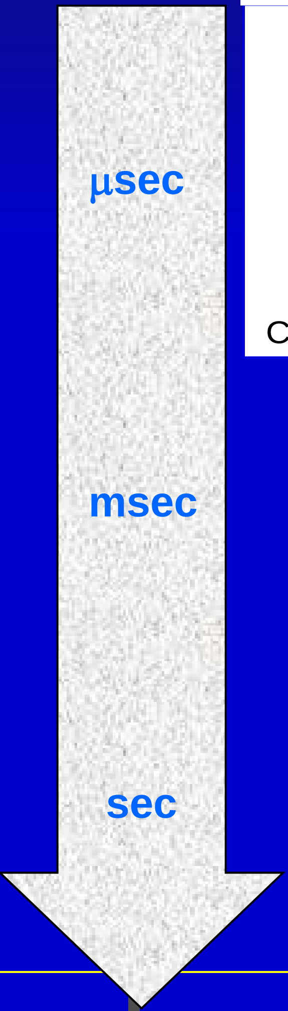




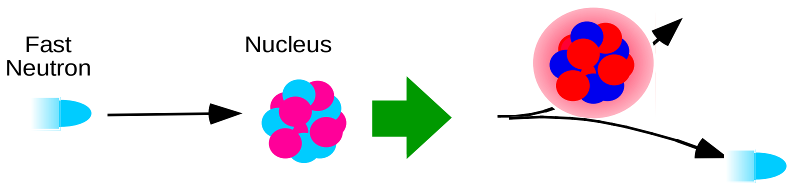


Principle of C/O Logging

Interaction Time Scale

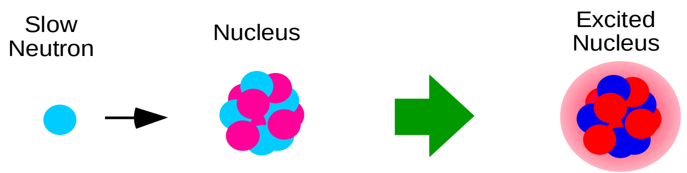


Inelastic Scattering



C, O, Si, Ca, Fe

Neutron Capture



H, Cl, Si, Ca, S, Fe, Gd,

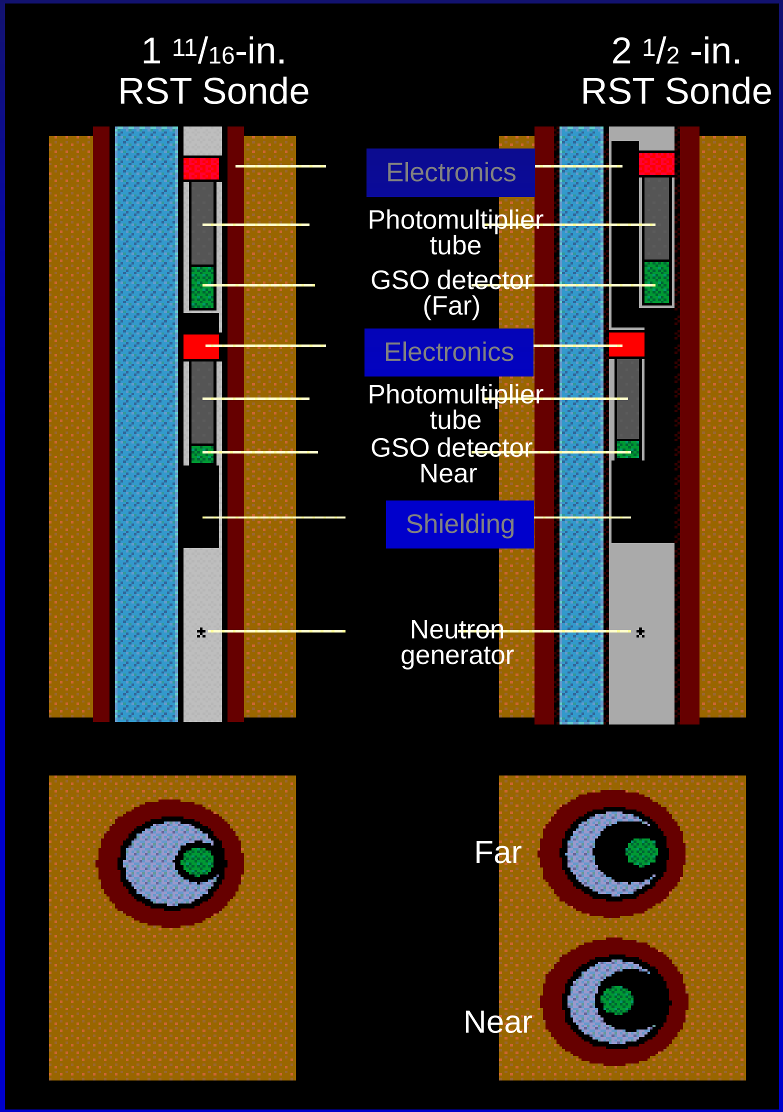
Inelastic or capture reaction that leads to a radioactive element and decay. Examples:

O-activation	$T_{1/2} = 7.1$ s	$(n + {}_8O^{16} \rightarrow {}_7N^{16} + ... \rightarrow {}_8O^{16} + \gamma + ...)$
Al-activation	$T_{1/2} = 2.3$ m	$(n + {}_{13}Al^{27} \rightarrow {}_{13}Al^{28} \rightarrow {}_{14}Si^{28} + \gamma + ...)$
Si-activation	$T_{1/2} = 2.3$ m	$(n + {}_{14}Si^{28} \rightarrow {}_{13}Al^{28} + ... \rightarrow {}_{14}Si^{28} + \gamma + ...)$

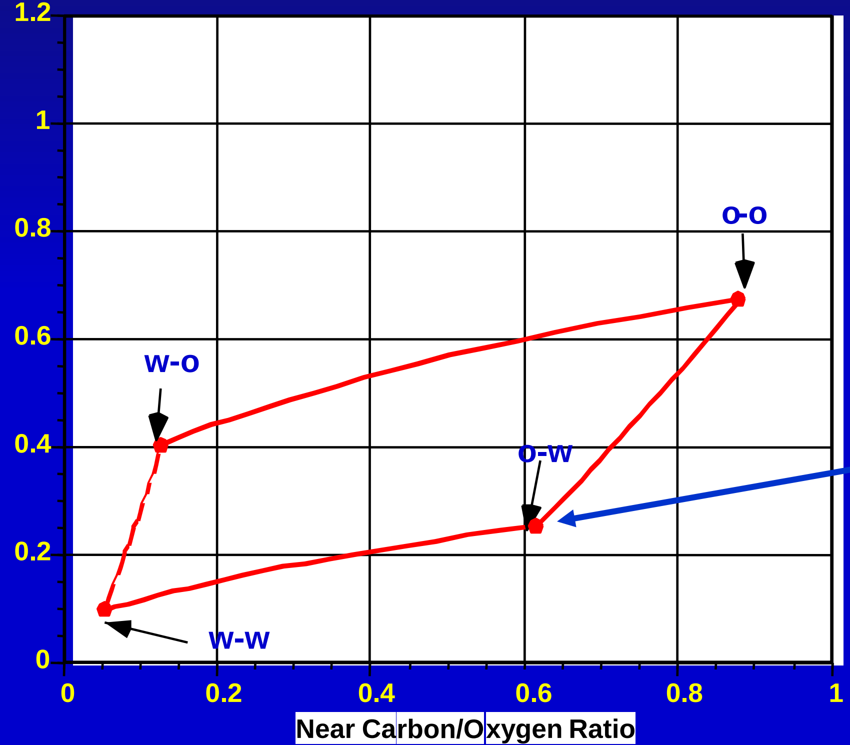
(Na, Cu, Fe..... and many more).

Factors affecting C/O response and available Tools

- Formation Fluid
- Borehole fluid
- Porosity
- Lithology
- Borehole size
- Casing size
- Casing weight



C/O Ratio and Water Saturation

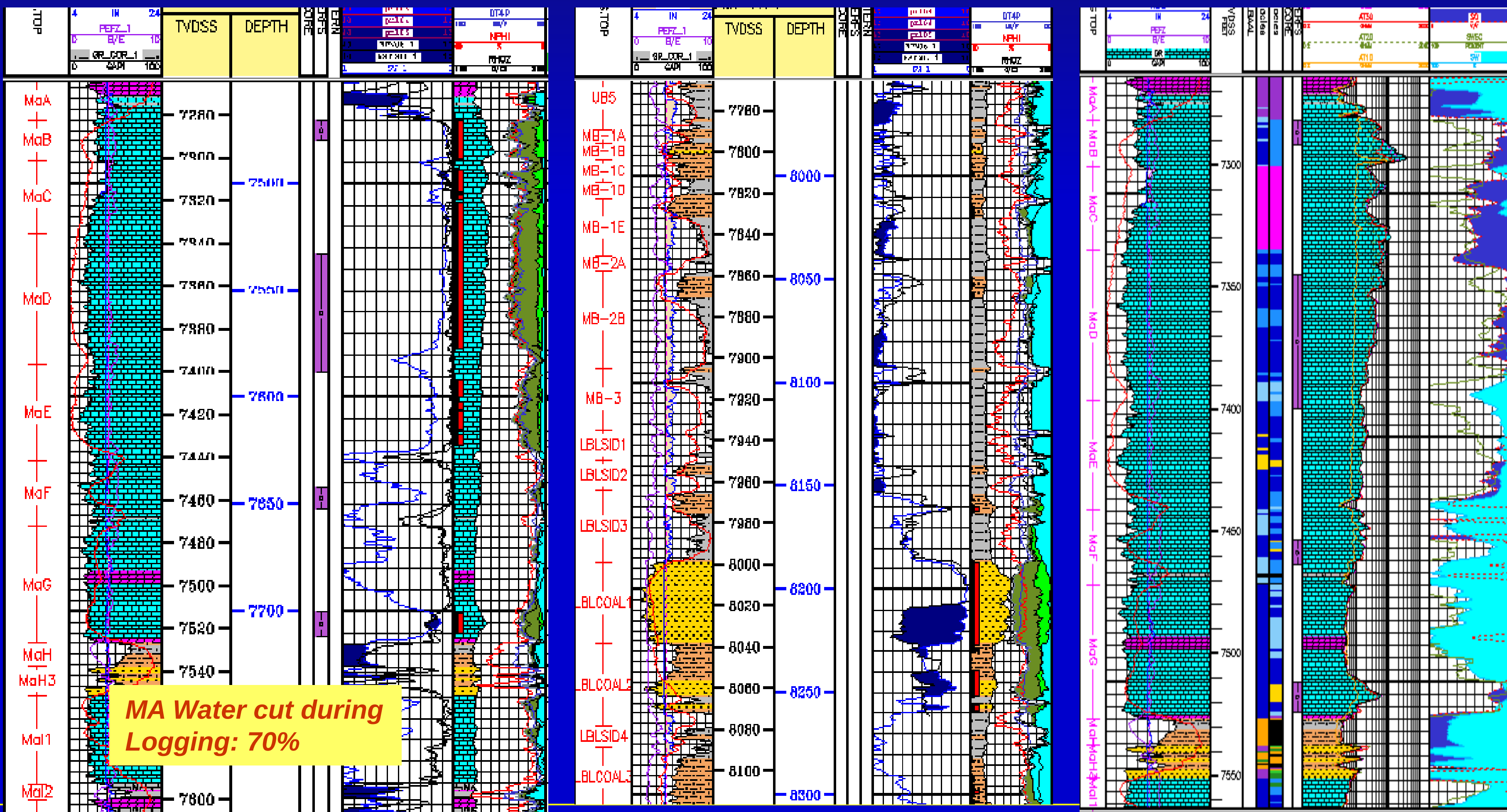


- Far and Near C/O response depend on Borehole and Formation fluids
- At this point
  - Oil in the borehole
  - Water in the formation

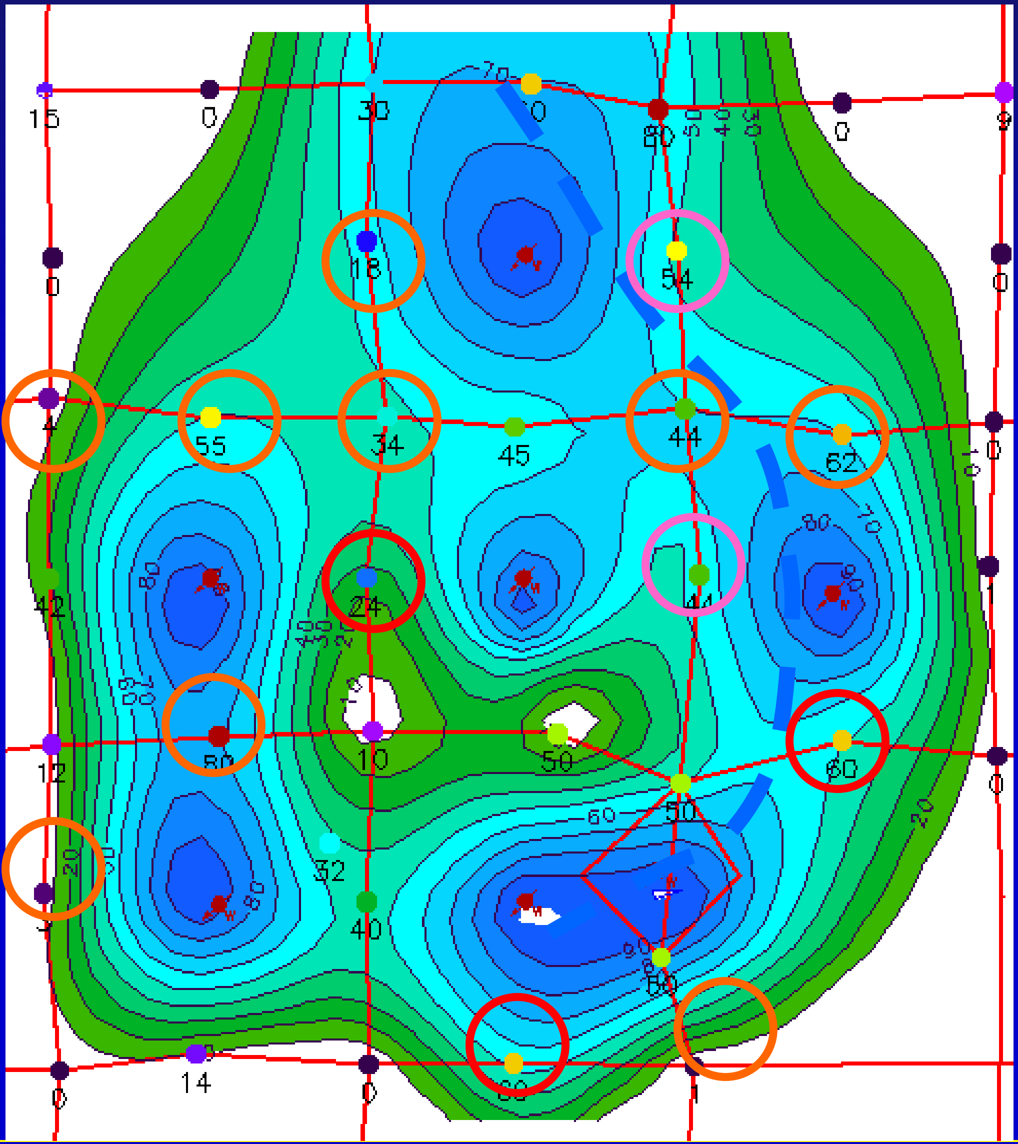
w-w:	water in borehole	water in formation
o-w:	oil in borehole	water in formation
o-o:	oil in borehole	oil in formation
w-o:	water in borehole	oil in formation

Significance of C/O Logging in Mauddud Waterflood

- Sigma log is insensitive: Low injected water salinity /Variable salinity in Formation (as seen in produced water)



Watercut in Mauddud at the time of C/O Logging

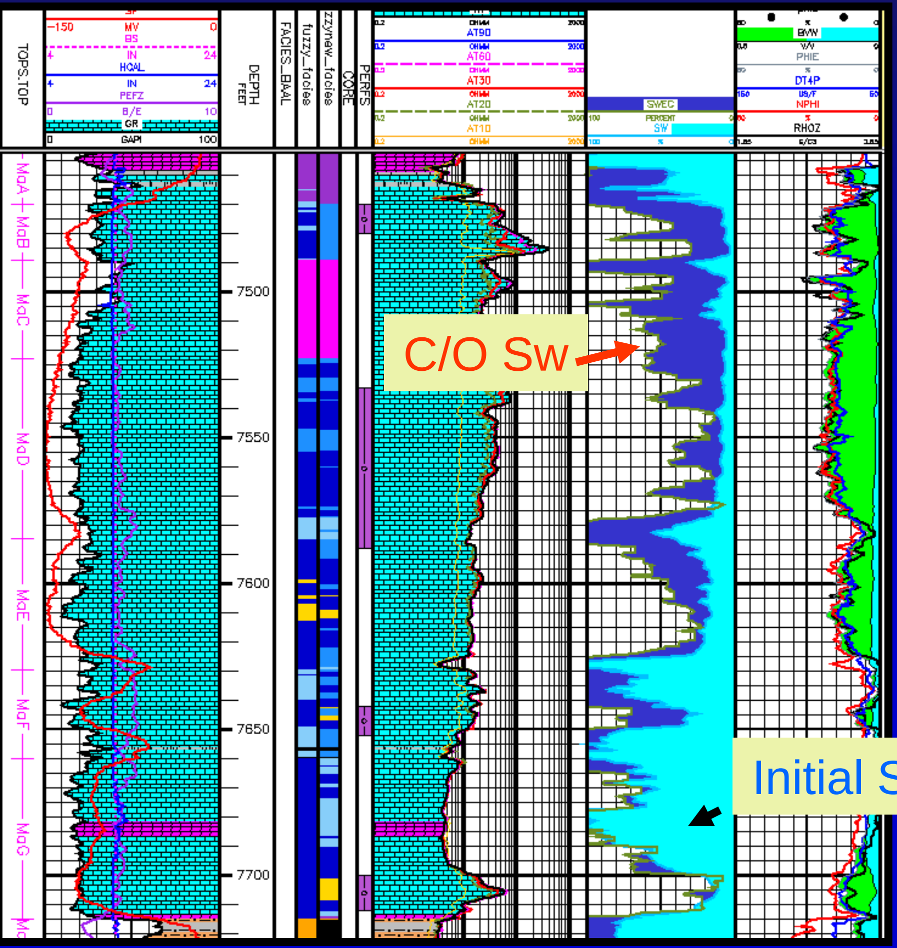


19 wells were logged for Sw

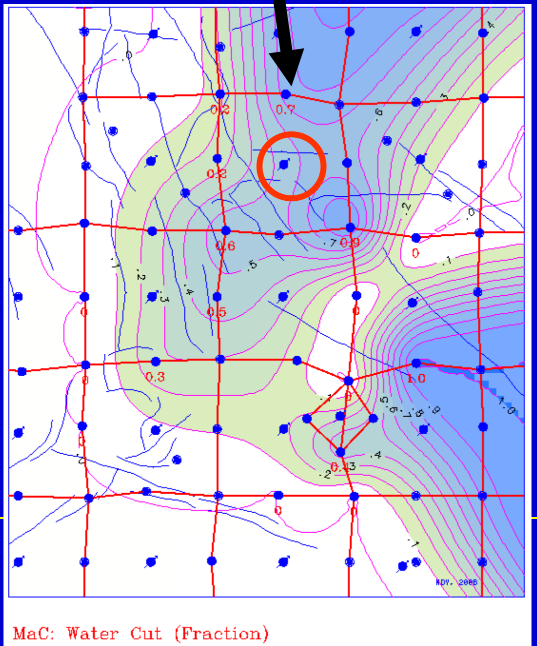
- *Different vendors*
- *Varying water cut*
- *Base line*

Analysis of C/O Log

26-Jan-07 **WC 60%**

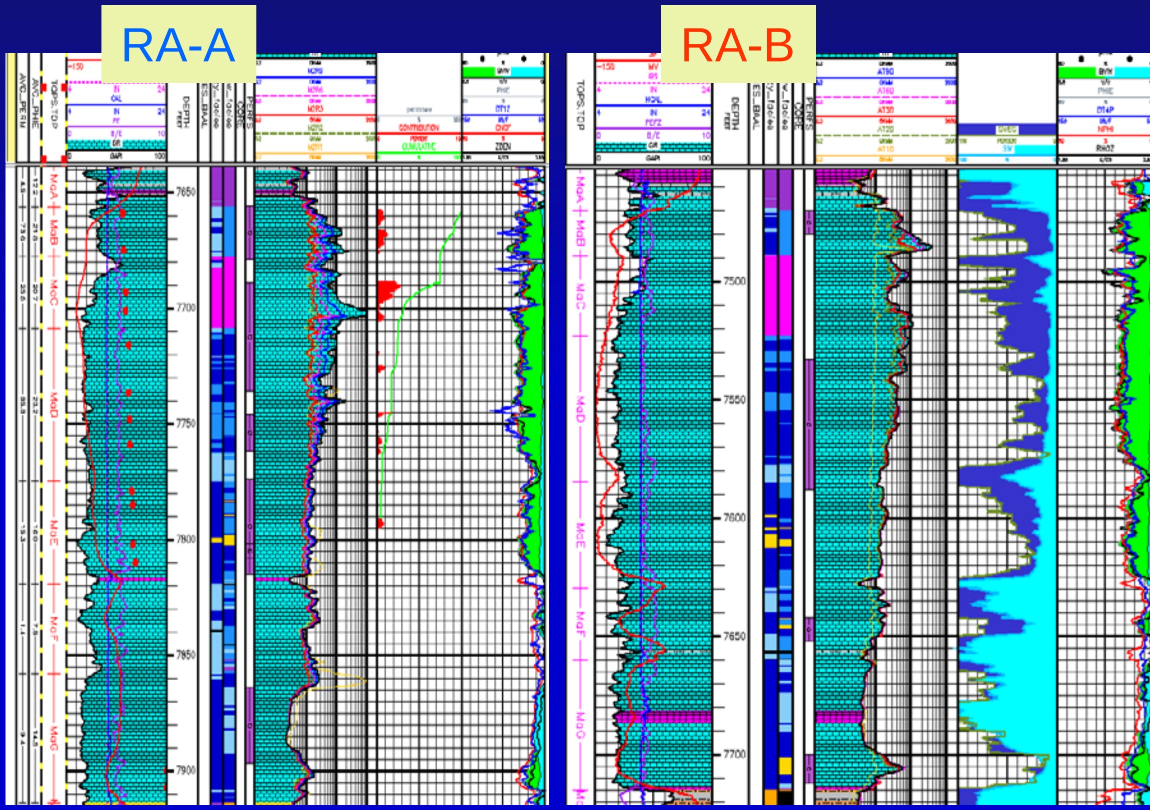


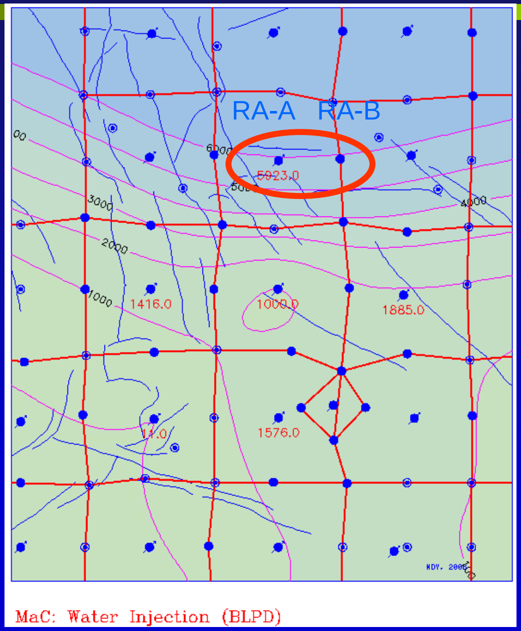
Water in un-perforated zone

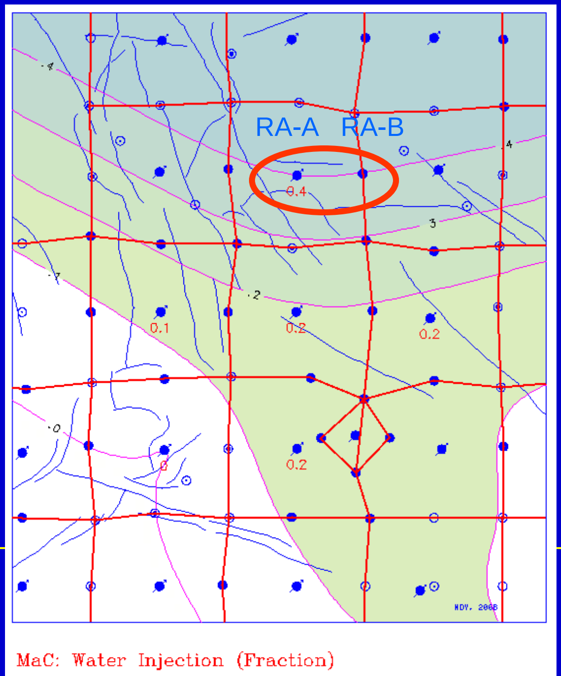


GOR: 450
API: 28

Water in MaC from nearby injector

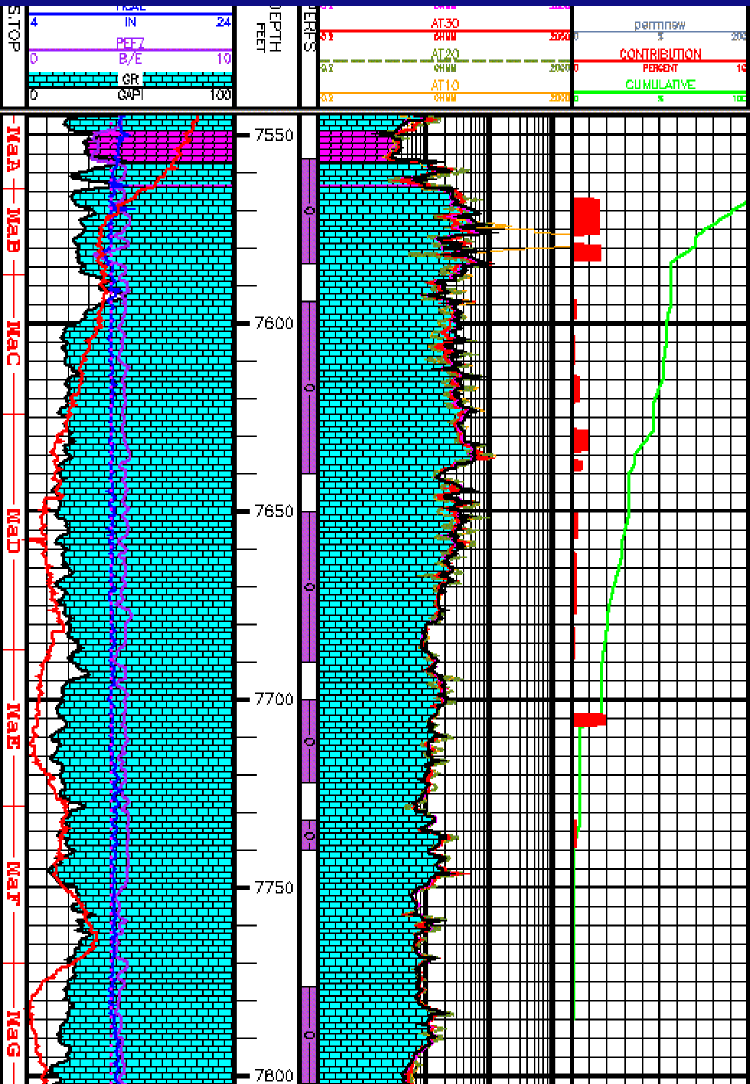






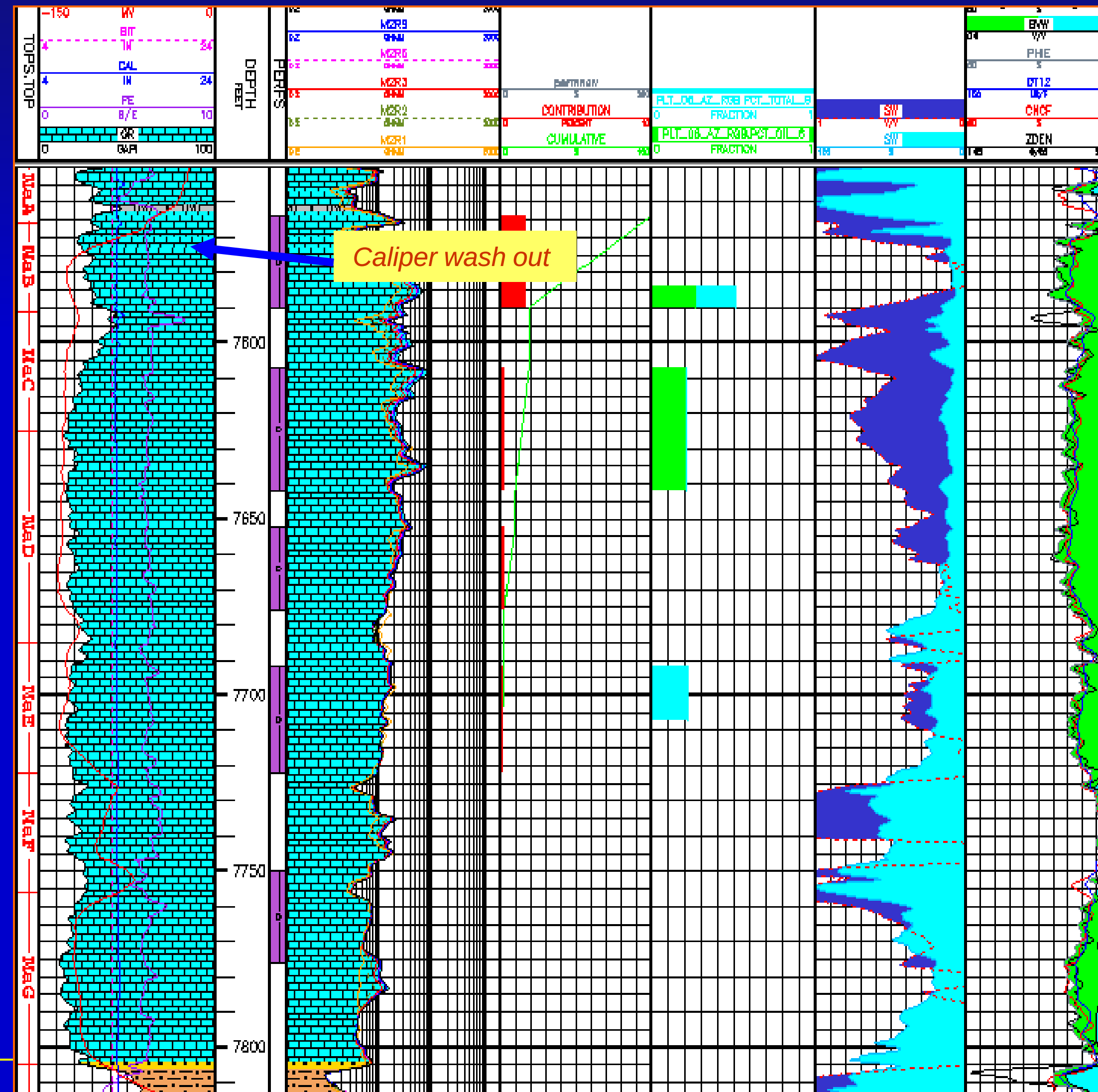
Water Saturation profile in Low porous zone

RA-e (Injector)



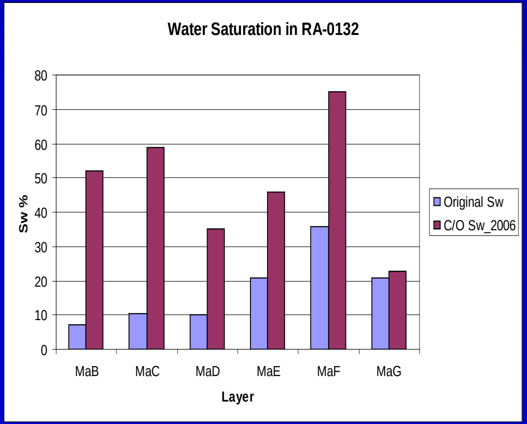
RA-D (Producer)

10-2001 *9-2006* **19-Feb-07**



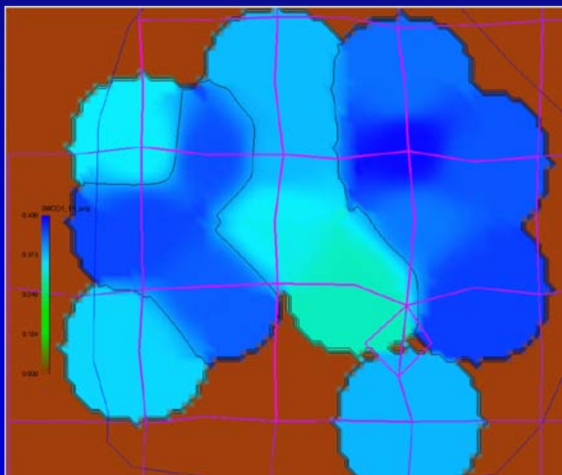
Modeling Sw from C/O

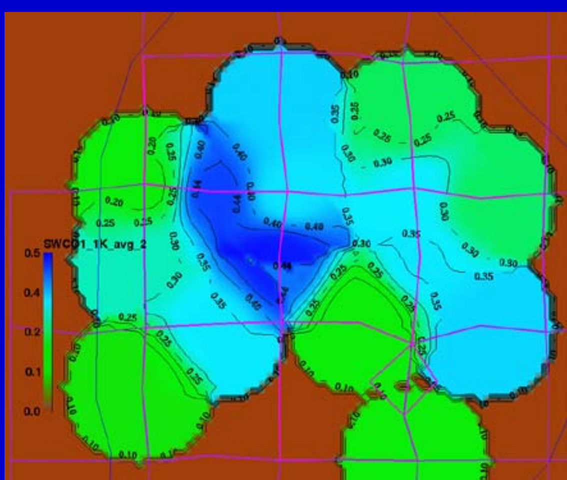
- Injected water: enters perforations and gets produced in from speed zones
- Stored in high effective porosity zones within the radius of encroachment
- Flag=1 for low porosity zones < 12
- SWCO1=SWCO IF Flag=1 SWCO1=Sw (Initial water saturation)
- IF SWCO1<Sw Then SWCO1=Sw
- SWDIFF=SWCO1-Sw
- SWCO1 and SWDIFF
  - ❖ Deterministic (Interpolated) and Stochastic (SGS/Co-Simulated)



Modeling water saturation from CO logs

SWCO1 interpolated with X=Y=1 Km, biased to structure





Flodded Zones (MaA-MaG)

Bypassed Oil

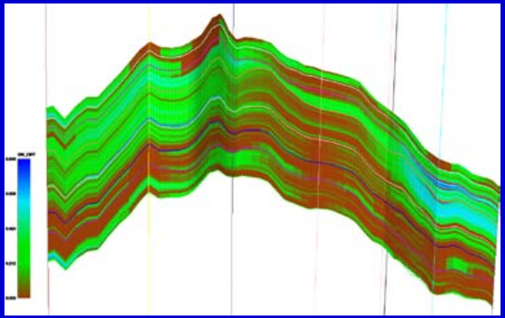
Swept Area

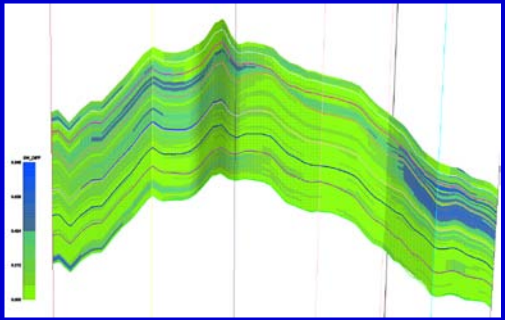
MaB Layer

Average Sw from Interpolation

Assumption:

- *SW from CO reflects K and PHI*
- *Permeability/effective porosity are layer bound: earlier flooding in high K & PHI*
- *SWCO1 of layers can be interpolated*

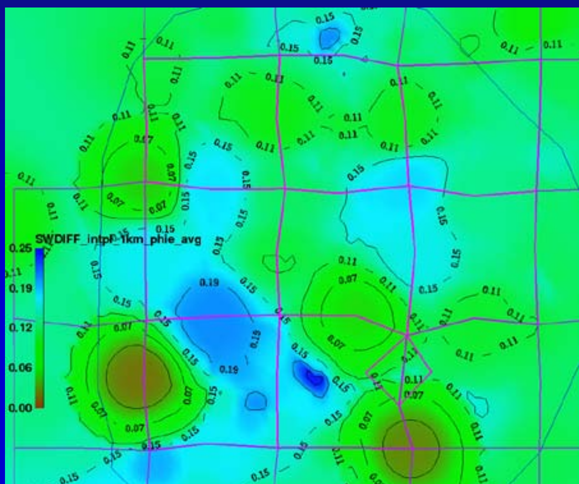




Modeling water saturation from CO logs

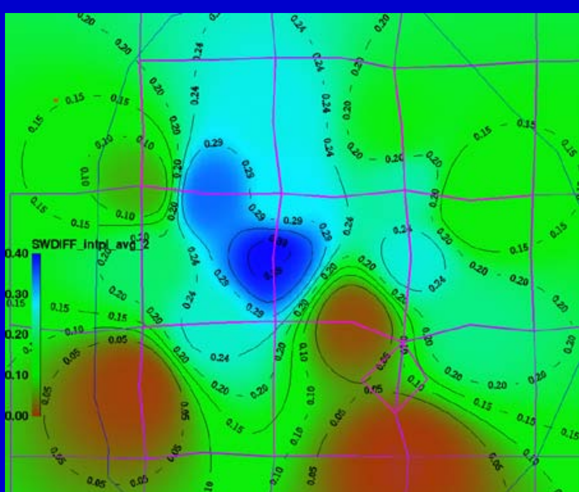
SWDIFF interpolated with X=Y=1 Km
Porosity used as trend with weight 0.20

Bypassed Oil *Swept Area*

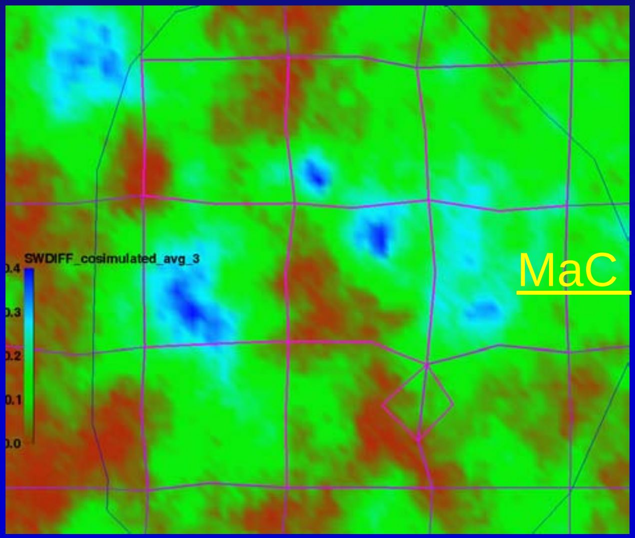


<u>*Layers MaA-G*</u>

SWCO1 unstable beyond 1Km due to short radius interpolation

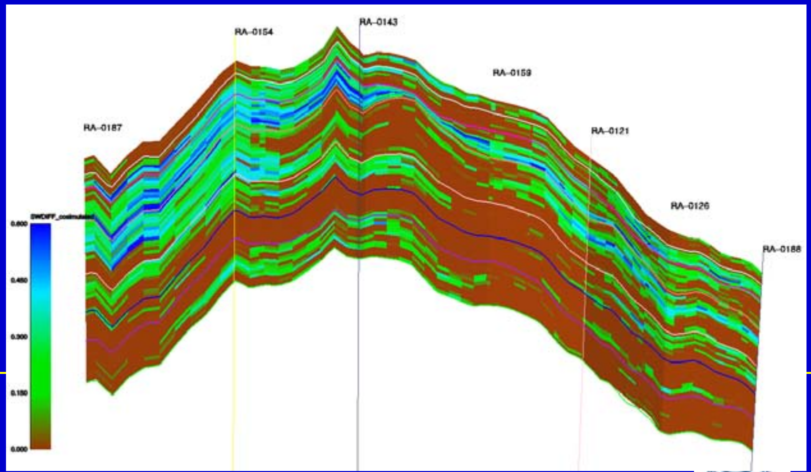


<u>Layer *MaB*</u>

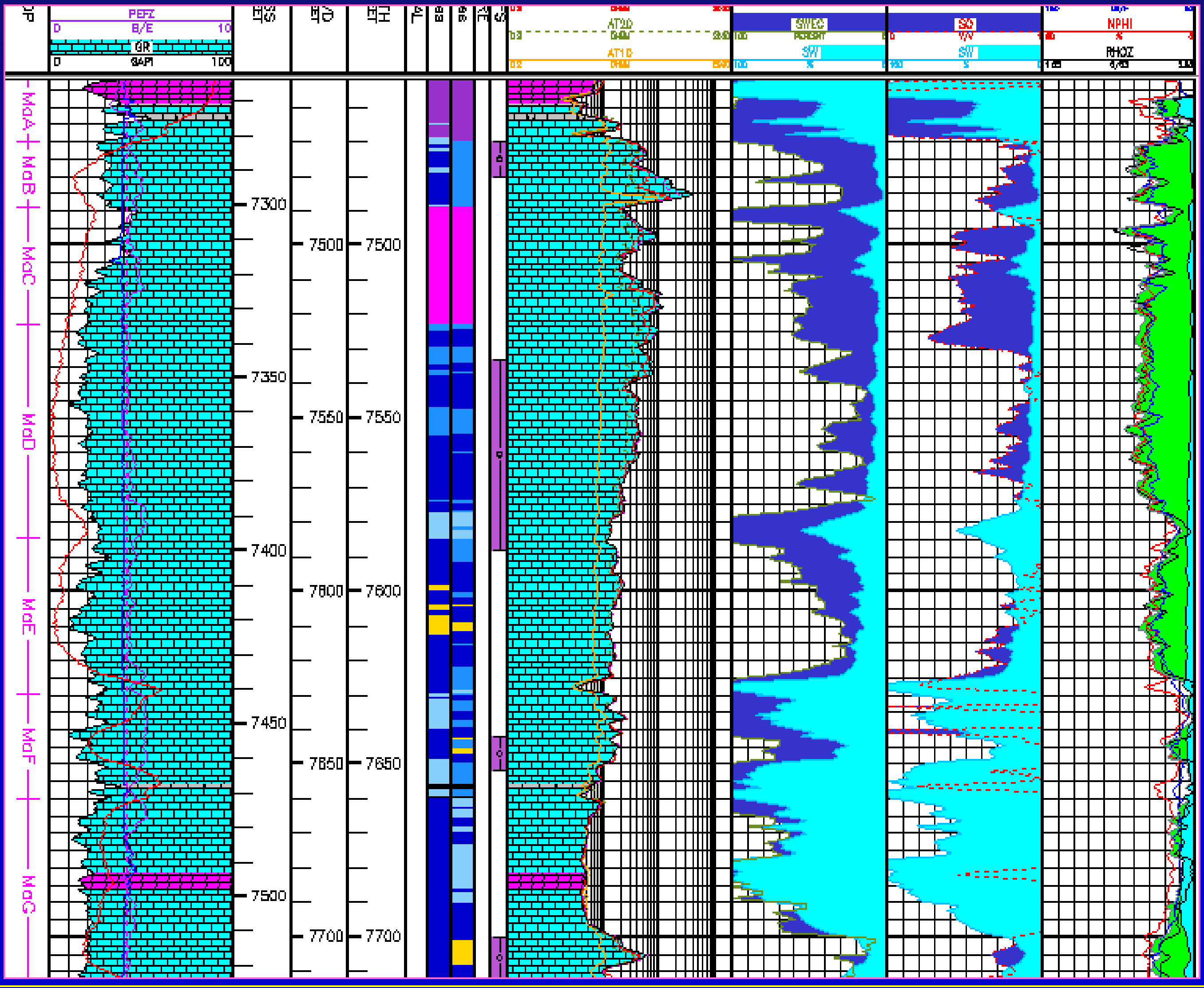


<u>MaC</u> Layer

SWDIFF Co-simulated with PHIE (CC:0.58)



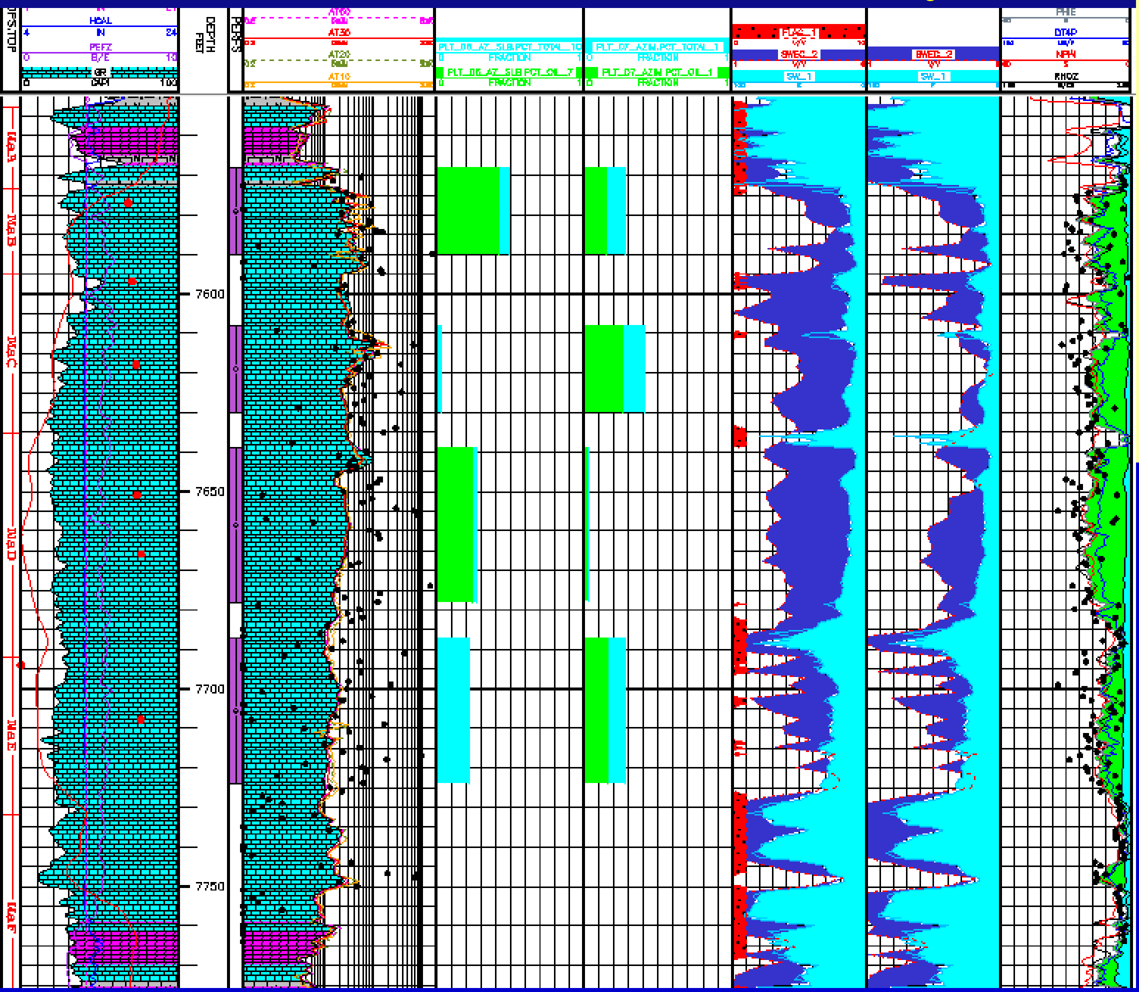
C/O Logging: Comparison with service companies and tools

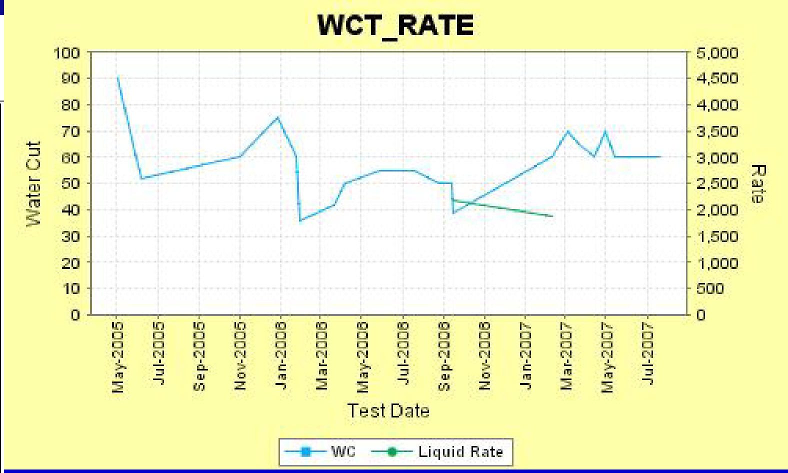


- *Logged within a week*
- *Major zones of encroachment similar*
- *Difference in Sw*

C/O sensitivity to Hold up

2006 2007 *Hold Up changed*





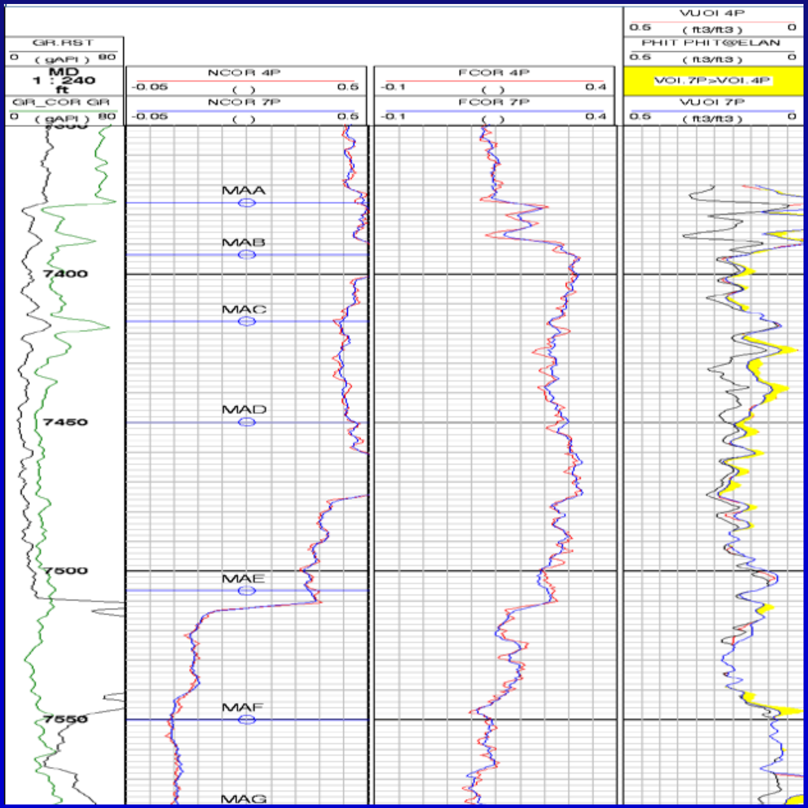
WC 60%

1 11/16” tool is subjected to uncertainty in hold up: use volume of water produced for Qc

Prior knowledge is not needed for 2 ½” C/O tool

C/O sensitivity

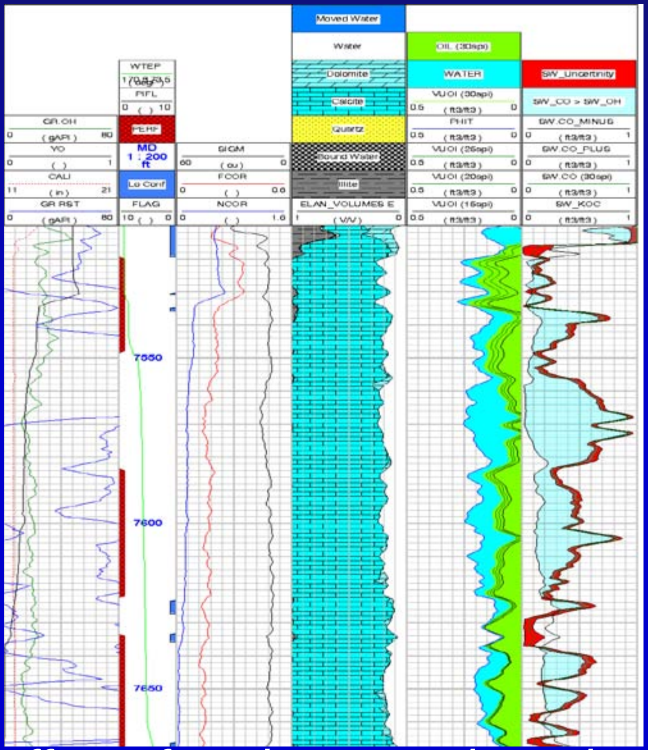
Logging passes



C/O logs have significant statistical variations:

- *Increasing number of passes reduces statistical error*

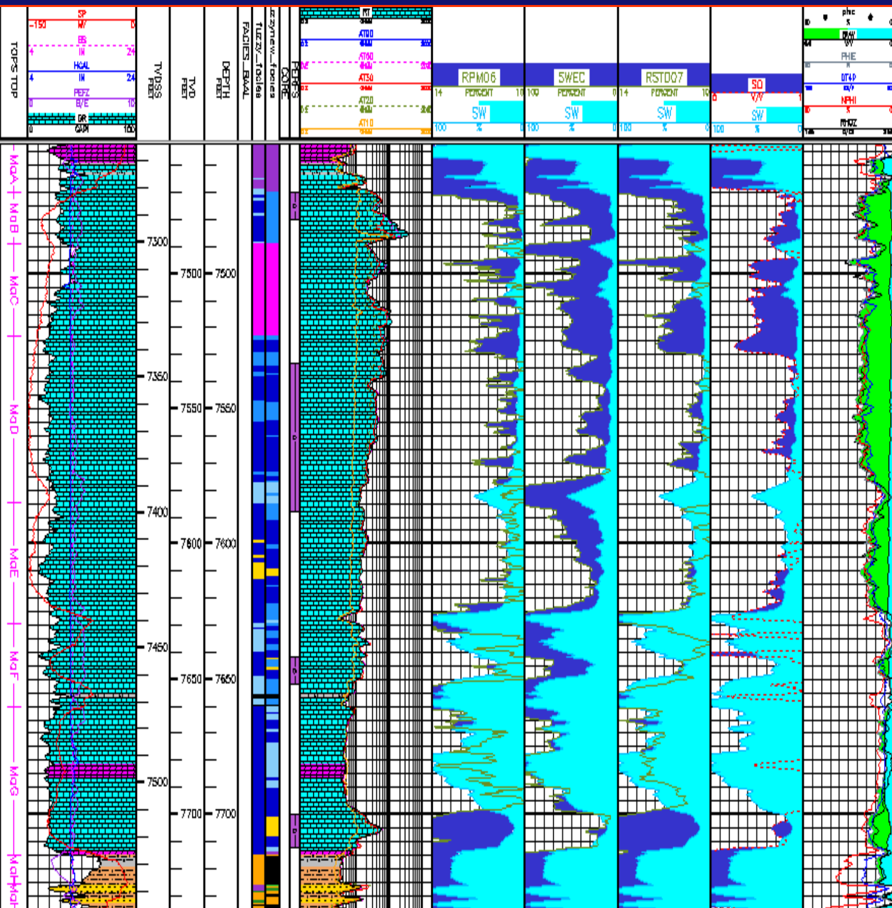
Oil Gravity



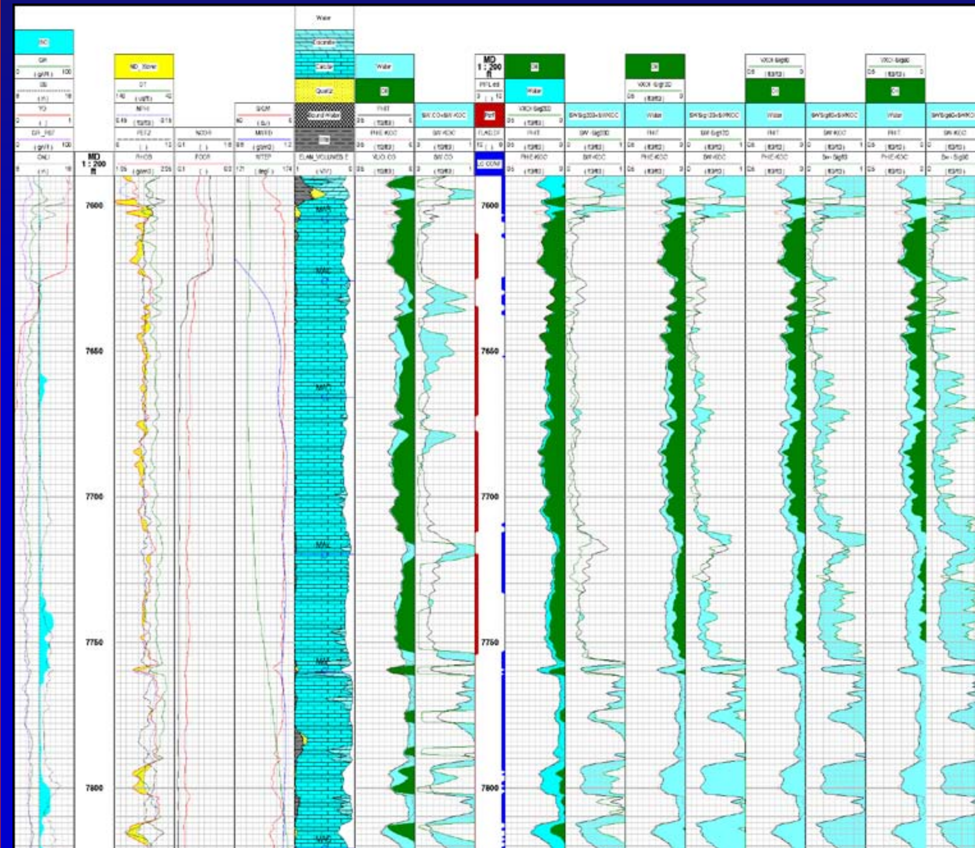
Effect of Carbon Density Value :

- *High CDV input lower Sw*
- *Up to 30% variation wiith 15-30 API oil*
- *Knowledge of API variation within a reservoir is critical for C/O based water saturation*

Can we use Sigma in place of C/O?



Sw from RST and Sigma with different salinities



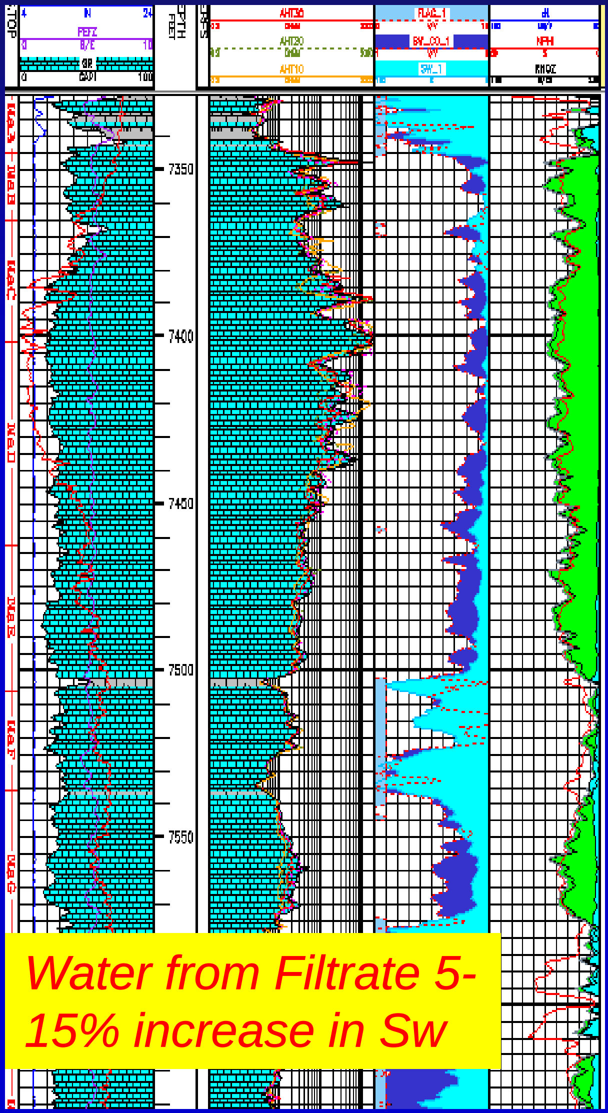
- *Display scales of sigma are changed*
- *Sometimes indicated flushed zones*
- *But not always*

Sw from sigma is not reliable due to:

- *variable water salinity*
- *Lower sigma contrast at lower salinity*

Limitations of C/O in Mauddud Reservoir

- Low Porosity zones: Fracture/thief zones
- Bigger Hole: 12 1/4" hole, 9 5/8" casing
- Dual Completions
- Invasion effect
  - ❖ROI 10"
- **Sw from C/O could be 1.2 to 2 times Higher than actual**
  - ❖Investigated with volumetrics
  - ❖Due to uncertainty in hold up



Conclusions-I

- Carried out an integrated study using C/O log water saturation from 19 wells with
  - ❖ production logs, well performance, core data and structure for evaluating
    - sweep, saturation monitoring and thief zone identification
- C/O logs have been quality checked and optimized for
  - ❖ different vendors, available tool sizes, number of logging passes, oil/water contribution from PLT, actual volume of produced oil/water and effect of oil gravity
- The integrated approach enabled
  - ❖ identifying thief zones in perforated and unperforated layers in wells and mapping their areal distribution

Conclusions-II

- Stochastic and deterministic water saturation models biased to petrophysical and structural trends were used to identify
  - ❖ swept zones and bypassed oil.
- Quantitative results from C/O logs were useful in high porous zones only when
  - ❖ the effects of hold up, filtrate invasion, oil quality and Shale volume were properly accounted for.
- Qualitatively useful for water flood monitoring, planning infill wells and in formulating perforation policy to target bypassed zones while avoiding thief zones.
- Application of C/O saturation needs integration with other static and dynamic data.