Charge History Clues from Advanced Geochemical Mud Gas Logging*

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Abstract

Mud gas logging provides an initial insight into reservoir fluids while drilling. Despite providing information only on the light end of petroleum fluids (methane to pentanes), its strength lies in its good depth resolution and continuity along the borehole. Developments in the last decade have equipped traditional mud gas logging with advanced degassing systems and geochemical analyzers known as advanced mud gas logging (AMGL) tools. Geochemistry-wise, critical new measurements developed included key C_6-C_8 isomers and a game-changing continuous high-resolution carbon stable isotope composition of methane (expressed as $\delta^{13}C$-C_1).

The AMGL has opened novel avenues of interpretation of mud gas data. One of the added values is the while-drilling quantification of gaseous alkanes per unit volume of rock in conventional reservoirs and the recognition of common petroleum-alteration processes. These processes include mixing thermogenic and biogenic fluids, biodegradation of petroleum, and phase separation and leakage via cap rocks, among others. Identifying fluid alterations prevents the mistyping of petroleum fluids based solely on classical gas ratios.

In-house AMGL methodology involves novel interpretative fluid-typing and alteration-flagging tools. The C_1 isotope logging can indicate direct maturity proxy with some limitations. The combination of $\delta^{13}C$-C_1 log with advanced mud gas molecular data while drilling, has enhanced the traditional Schoell diagram with six thermogenic fluid types along vitrinite reflectance equivalent (VRE) maturity isolines, and a level of mixing with biogenic C_1. Additionally, there are workflows with advanced interpretation diagrams: spider plot, modified Bernard, gas wetness versus character, C_2/iC_4 versus C_2/C_3, parent fluid fingerprinting iC_4/nC_4 versus $\delta^{13}C$-C_1, and diffusion-leakage versus migration-mixing $\delta^{13}C$-C_1 versus C_2/C_1.

This toolkit enabled the development of new interpretation decision-trees for higher confidence of fluid-typing and fluid-alterations flagging. As such, this AMGL methodology (molecular composition coupled with C_1 isotope signature) provides early information on petroleum systems, especially charge history, enabling targeting of specific mobile fluids for further analyses, leading eventually to their production.

Charge History *Clues* from Advanced Geochemical Mud-Gas Logging

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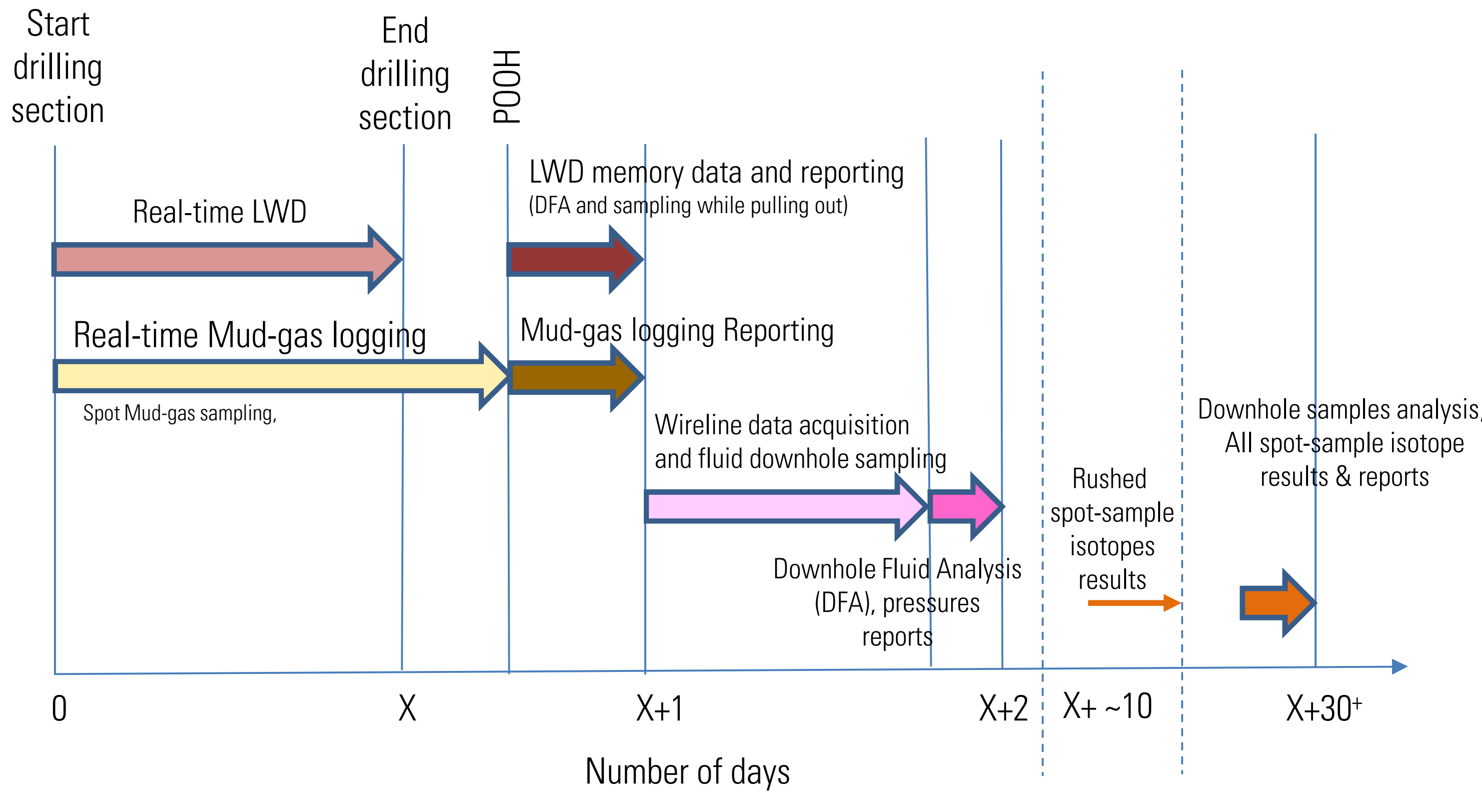
Timeline of delivery

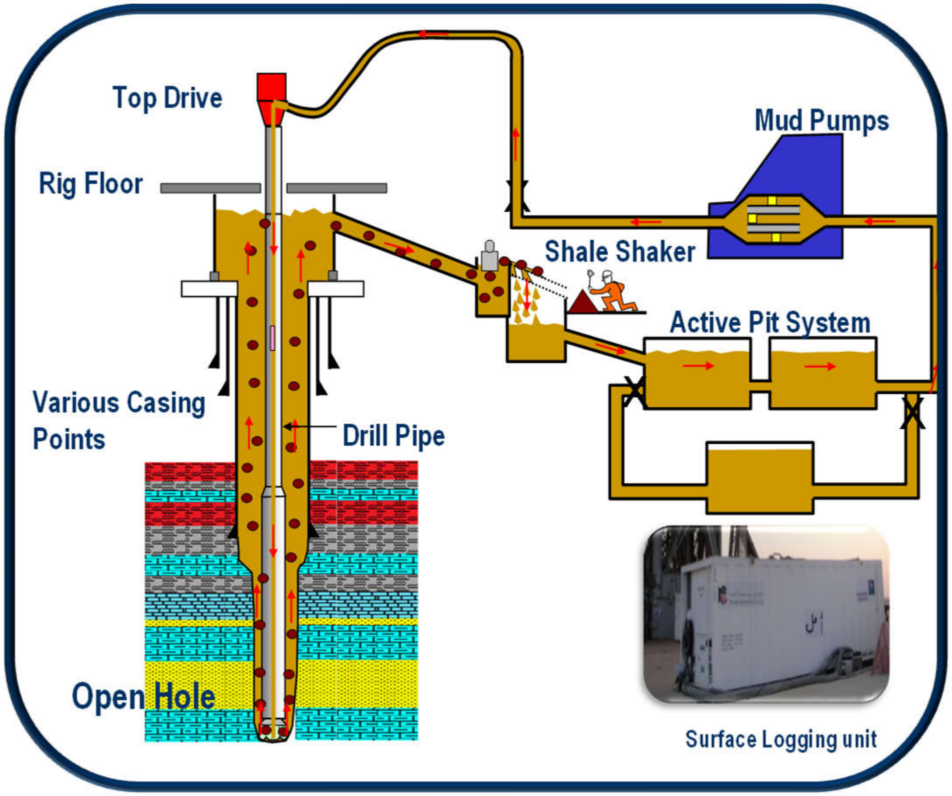


Agenda

- Introduction to mud-gas logging and interpretation
- Advancements on mud-gas logging
- Light-end fluid composition logging
  - Real-time clues from light-end fractions
- Conclusions

Mud-gas Logging

- Formation fluids are released from the pore space by the crushing action of the bit
- Fluids released into the mud are expected to be either
  - Dissolved in mud phase (OBM or WBM)
  - Adsorbed on solids
  - Free phase
- Analysis of light hydrocarbons by vaporization in gas extractors at specific locations



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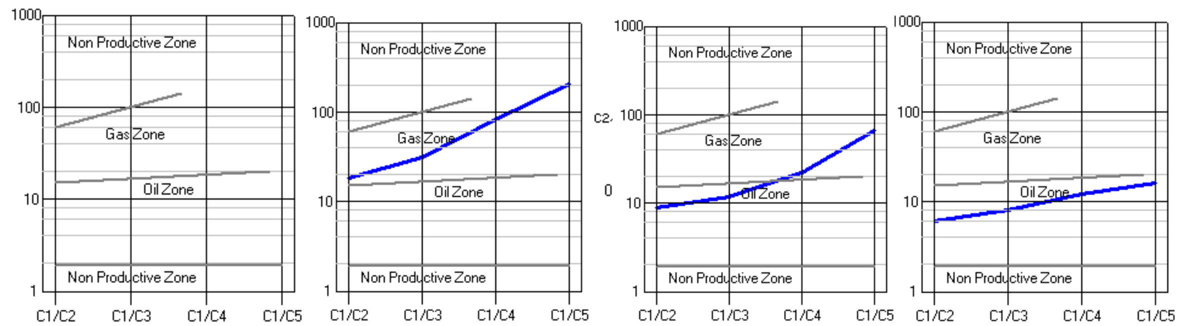
Fluid Characterization – Mud-gas Ratios

(PIXLER 1968, HAWORTH et al 1985, WHITTAKER and SELENS 1987, WHITTAKER 1991, WRIGHT 1996)

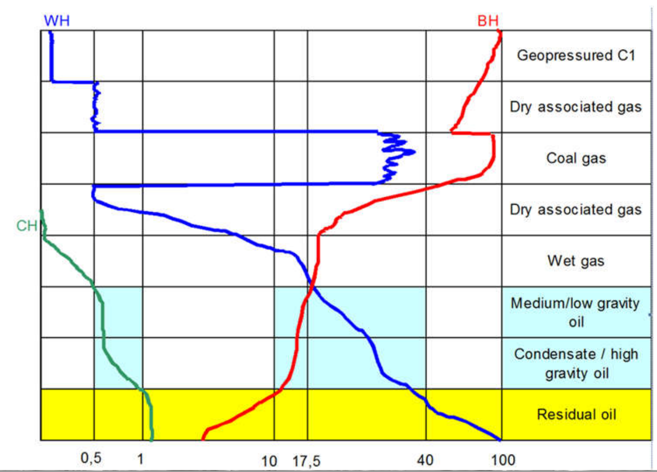
Single plots:

- **Triangular diagram** **(C2/CT, nC4/CT, C3/CT)**
- **Pixler plots** **C1/C2, C1/C3, C1/C4, C1/C5**
- **Spider diagram** **(multiple ratios)**
- **Cross plots** **C1/C2, C1/C3, etc.**



Continuous plots:

- **Wetness (Wh)** **{(C2+C3+C4+C5) / (C1+ C2+C3+C4+C5)} X 100**
- **Balance (Bh)** **(C1+ C2) / (C3+C4+C5)**
- **Character (Ch)** **(C4+C5) / (C3)**
- **Binary ratios** **- C1/C2, etc.**



- **Reliability highly depends on geographical area and petroleum context**
- **Plots need modification as they are very old and not updated**

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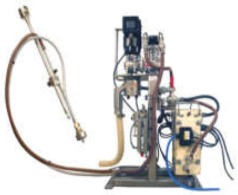
Advancement in mud-gas logging…

- Advancement in mud-gas extractor and gas analyzers enables quantitative gas analysis



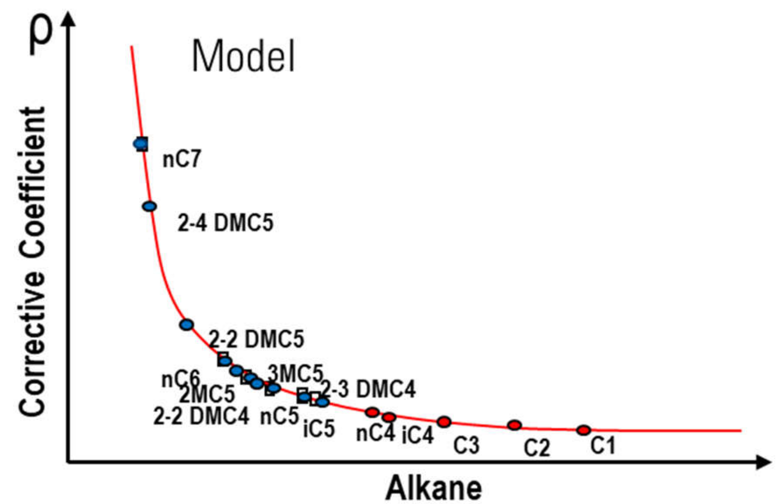
Controlled thermodynamics
1) Constant volume
2) Constant temperature
3) Constant pressure
3) Controlled agitation

GCMS
1) Higher resolution of peaks
2) Detection of more species of hydrocarbon and non-hydrocarbon
3) Quick cycle time
4) Analysis under vacuum conditions

CRDS (Cavity Ring Down Spectroscopy) for isotopes
1) Quantitative isotopic composition analysis on methane and ethane (future)
2) Specific QC equipment to remove contaminants
3) Cycle time is very short (below one minute)

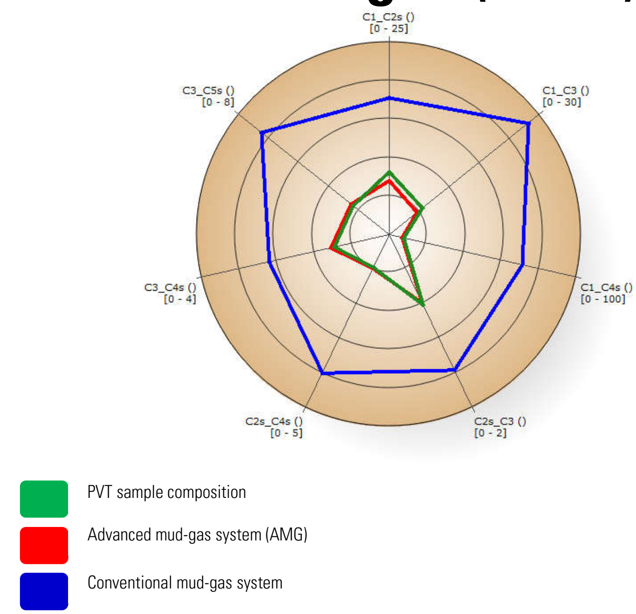
GCMS: Gas Chromatography Mass Spectrometer
CRDS: Cavity Ring Down Spectroscopy

- Specific processes and evaluation of the adsorbed and dissolved hydrocarbons allow quantitative measurement of hydrocarbons in mud



Standard vs Advanced Mud-gas (AMG)

Process	Conventional System	Advanced System
Extraction process	Extraction process not controlled	Smaller mud volume, higher agitation speed and constant high temperature for high efficiency
Extraction efficiency	Cannot be determined	Extraction efficiency determination for fluid compositional analysis
Analyzer	Flame Ionization detector, Output: C1-C5	GC separation and mass spectrometer, Output: Alkanes C1-C8, Cyclo Alkanes (MCC6), Aromatics (C6H6, C7H8) and Inorganics (CO2, He, H2)
Quality control	No means to verify quality of acquisition	Sensors to record operational integrity of equipment



Effect of extraction conditions on measurement.
Advanced mud-gas = PVT sample composition
Conventional system gives lighter fluid

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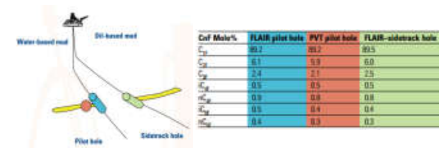
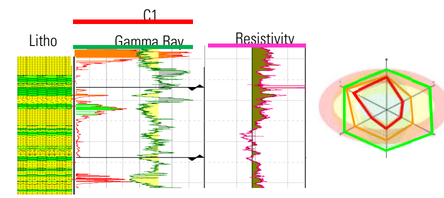
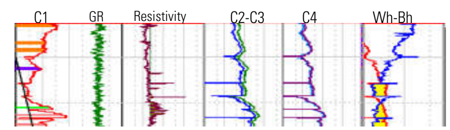
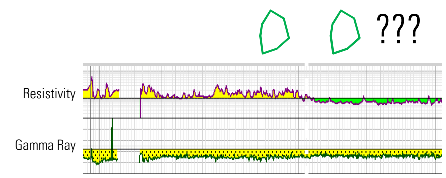
Fluid Fingerprint in Various Scenarios

Cross-well Correlations	►	Vertical and horizontal connectivity
Complex Reservoirs	►	Multilayered system with variable porosity
Thin Beds / LRP	►	Hydrocarbon presence in thin beds (low-resistivity pay)
Support to Geosteering	►	Remain within target
HPHT	►	De-risk and optimize formation testing and sampling in HPHT well



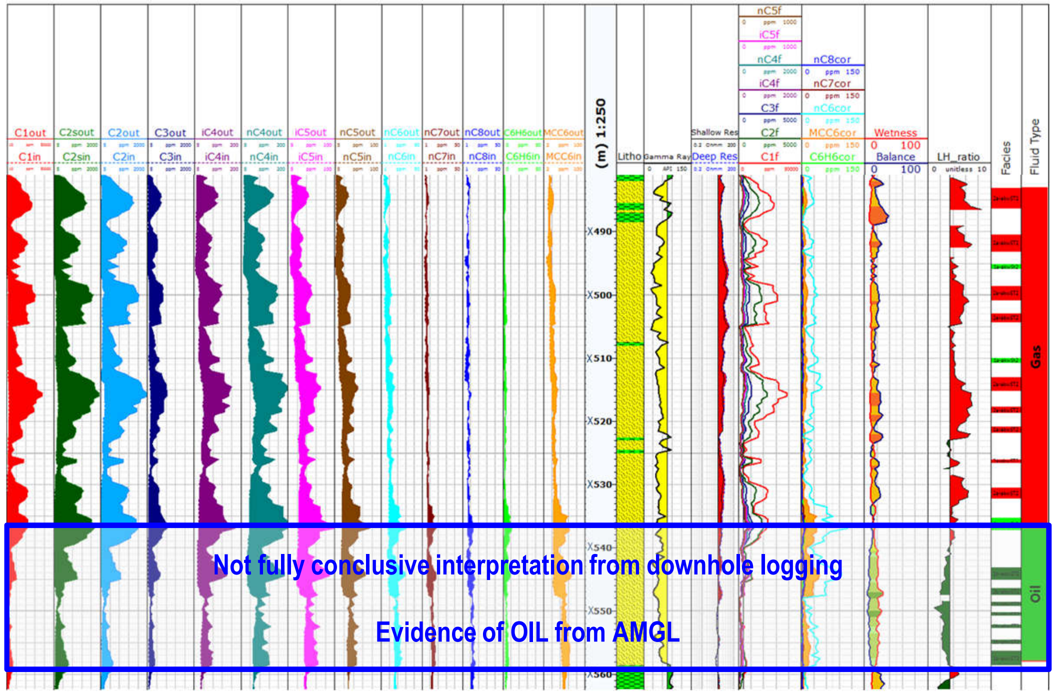






Additional information from C6+ logging

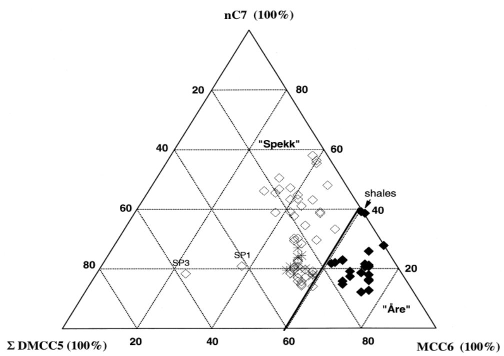
- C6+ hydrocarbons are always part of the liquid phase
- Allows enhanced characterization of formation fluids
- Enables identification of contacts and transition zones
  - differentiation between gas-oil and oil-water contacts



I. Fornasier et al., "The essential Role of the Advanced Surface Fluid Logging in the Reservoir Fluid Evaluation Workflow". SPWLA 56th Annual Logging Symposium, July 18-22, 2015.

Additional information from C6+ logging

Source rock characterization (W. Odden et al., 1998)



C6-C7 fluid fingerprinting (W. D. Masterson et al., 2001)

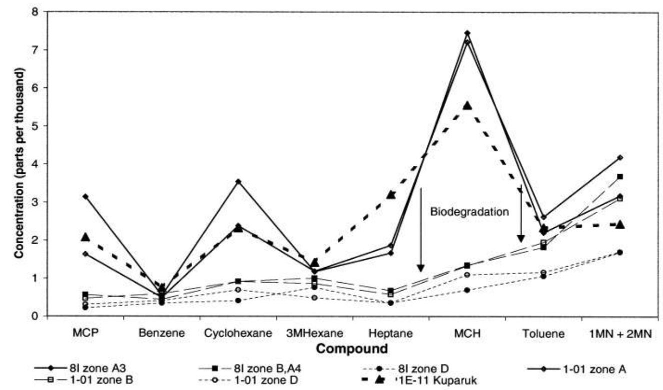
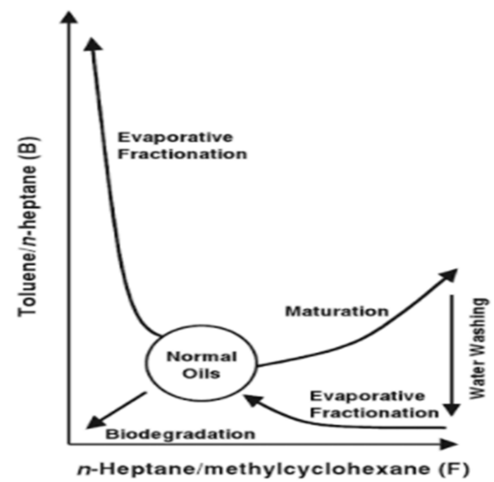


Fig. 11. Concentrations from whole-oil gas chromatography of selected compounds in six West Sak field oils and in the 1E-11 oil from the Kuparuk field. The relatively high concentrations of methylcyclopentane (MCP), cyclohexane, and methylcyclohexane (MCH) in the West Sak zone A oils are also evident in the underlying Kuparuk field oil.

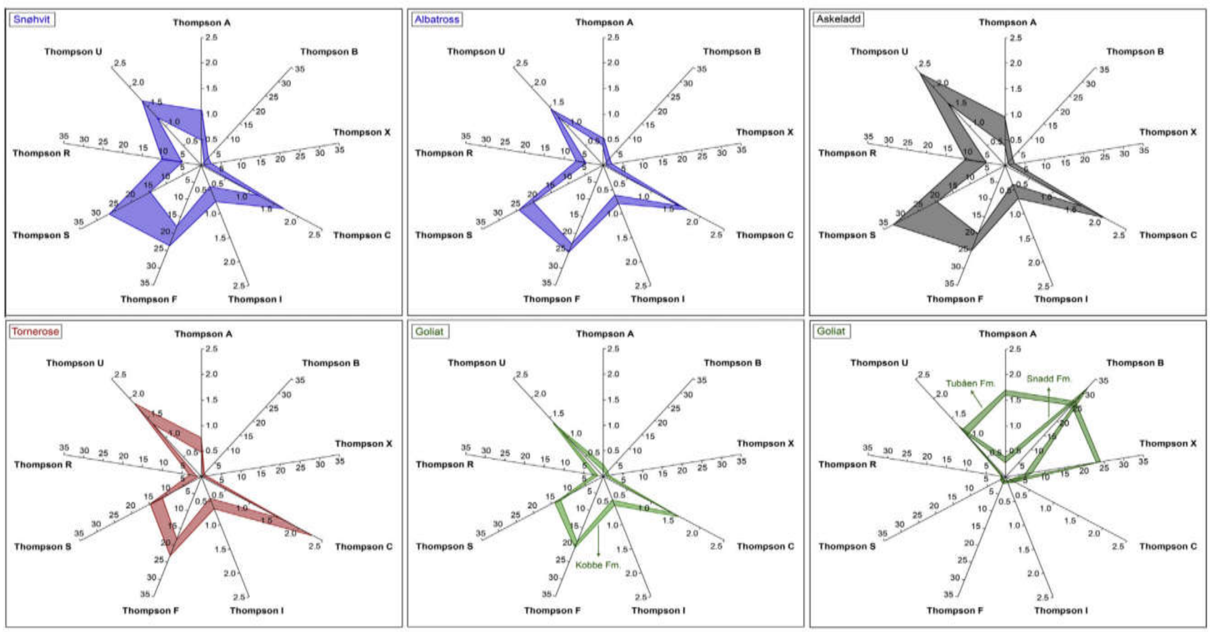
Alteration processes (Thompson, 1983)



Currently a qualitative approach by advanced mud-gas logging

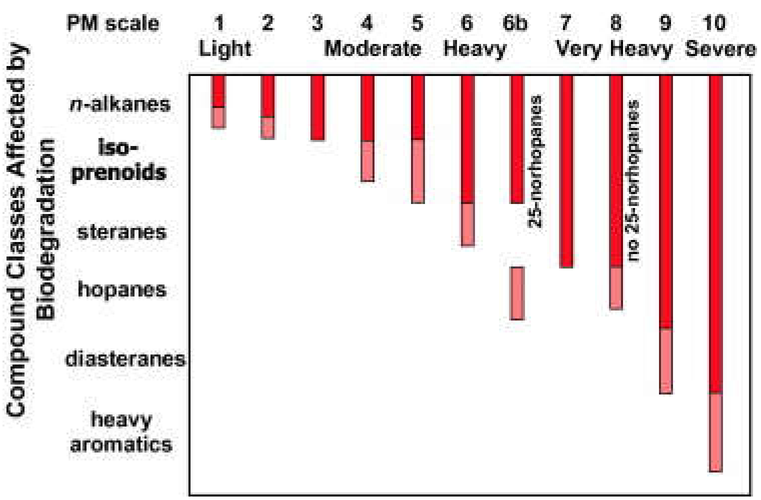
C6-C7 Isomers Applications

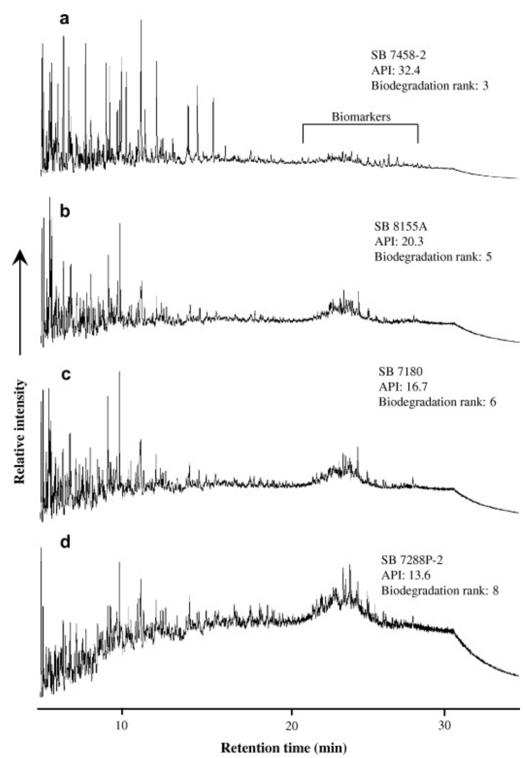
Thompson Star Plot



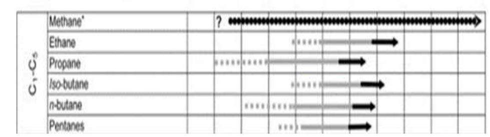
Name	Ratio	Process
A	**Ben/nC6**	• Fractionation • Water washing • TSR
B	**Tol/nC7**	
X	~~mXylene + p-xylene/nC8~~	
C	**nC6 + nC7/CC6 + MCC6**	• Maturity • Biodegradation
I	2- + 3-MC6 + ΣDMC5s	• Maturity • Biodegradation • Source
F	**nC7/MCC6**	• Maturity • Biodegradation
H	~~100 x nC7/ΣCC6 + C2HCs~~	• Maturity • Biodegradation • Source
S	**nC6/2,2-DMC4**	
R	nC7/2-MC6	
U	**CC6/MCC6**	• Maturity • Source

Biodegradation.





	Level of biodegradation										
Scale of Wenger et al. (2003)	Non	VS	S	M	H		Severe				
Biomarker Biodegradation Index Peters et al. (2005)	0	1	2	3	4	5	6	7	8	9	10
API gravity*	36	32	31	28	20		5-20				
Total acid number (mg KOH/g oil)*	0.2	0.5	1.0	1.5	2.0		2.5+				
Gas oil ratio (kg gas/kg oil)*	0.17	0.16	0.12	0.08	0.06		< 0.04				
% C15+ saturated hydrocarbons*	75	70	65	60	50		35				



Propane goes first.
Ethane last.

The abundance and distribution of diamondoids in biodegraded oils from the San Joaquin Valley: Implications for biodegradation of diamondoids in petroleum reservoirs, Zhibin Wei et al, 2007

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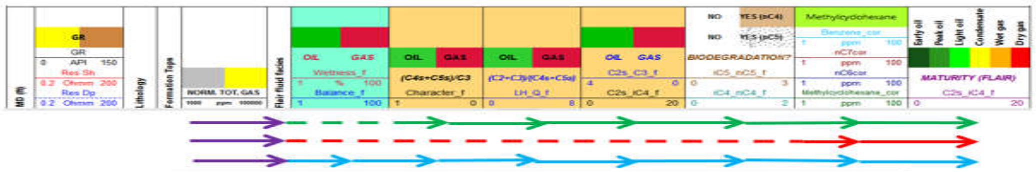
Workflows: AMG – molecular composition



Is it HC-rich zone? (Relatively high NORM.TOT.GAS.)

Are indications of liquid OIL or GAS consistent?

Ex. Wetness/Balance indicating GAS but C2+ tracks (Character, LH_Q and C2_C3s/C2_C4) indicate OIL?

All OIL tracks are green? All GAS tracks are red?

NO

Biogenic C1 present.

OR

Mature gas re-charge into oil reservoir
Note: All ratios might be affected due to mixing of two different thermogenic fluids. Use ratios with care. E.g. if 100% dry gas re-charge, use all C2+; if C1+C2 re-charge, use Ch, C6+ & i/n only If re-charge has all C1-5s, only C6+ can indicate primary liquid charge.

Thermogenic component biodegraded?
(infills on BIODEGRADATION track* & C2/C3 increased) ?

NO (mix with primary biogenic C1). Use:
- C2+ ratios
- C6+ presence
- MATURIY (FLAIR)

YES. Use:
- MCC6 presence&
- MATURITY (FLAIR)*

YES

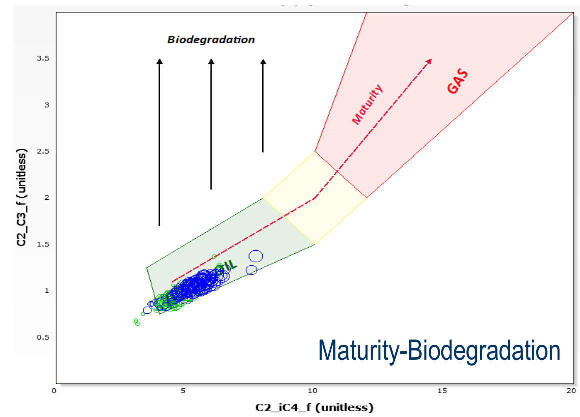
Possibly single charge unaltered fluid
Use:
- All OIL vs GAS tracks
- C6+ presence
- MATURIY (FLAIR)
- i/n ratios%

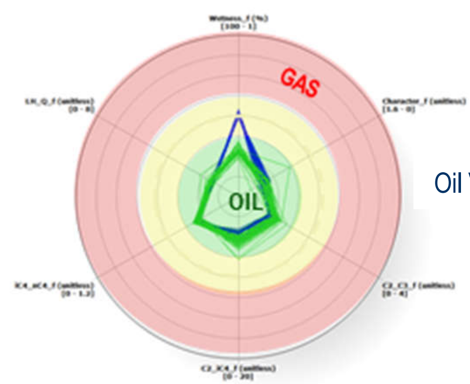
OR

Mix of biogenic C1 and mature thermogenic gas
Note: All ratios may consistently indicate gas, yet, C1-containing Wh/Bh might be the most red. Likely no C6+. Near cutoff i/n.

% i/n ratios can increase if kerogen III in Source Rock of fluid
* In heavy biodegradation cases, even C2 and iC4 will be biodegraded, and C2/iC4 ratio affected
& C_6-C_8 n-alkanes affected already at low level of biodegradation, methylcyclohexane as more resistant might be still indicative of initial charge of liquid fraction

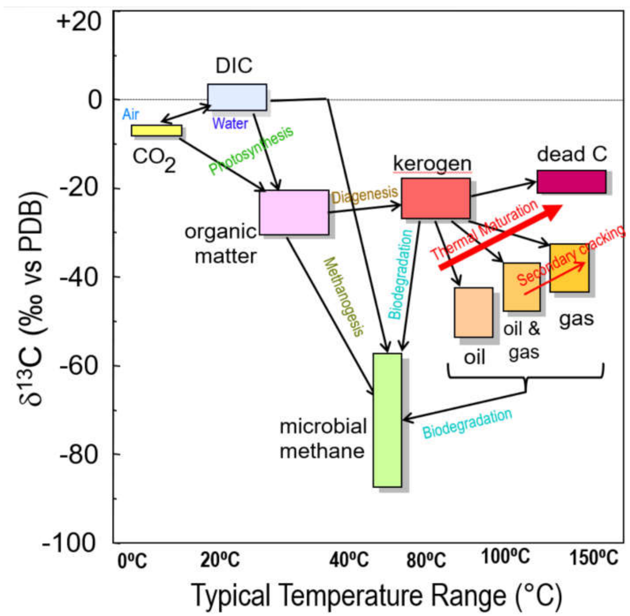
Higher i/n can be due to kerogen III contribution to the source rock of this fluid. If no bias from kerogen III, i/n can serve as an additional rough maturity proxies: for oils typically iC4/nC4 < 0.6 and iC5/nC5 < 1.0



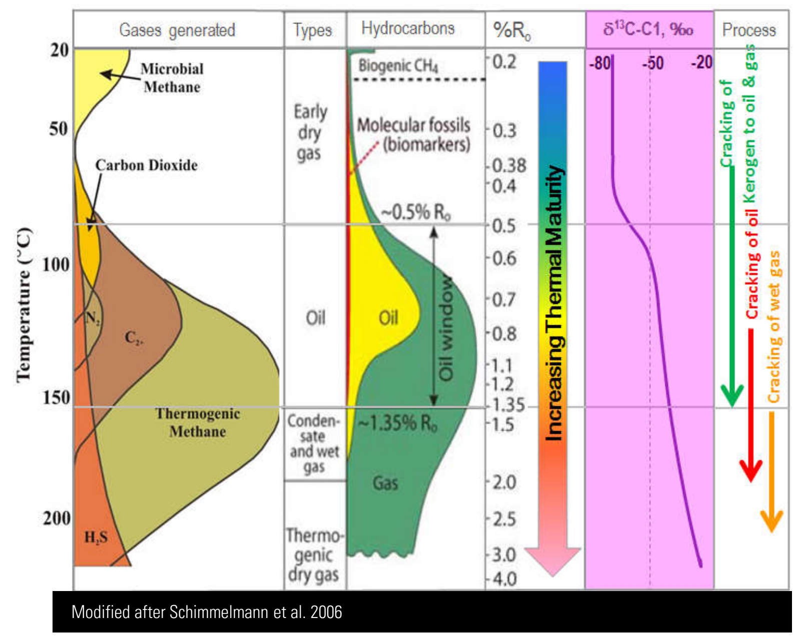


AMGL
Oil VS Gas Star diagram

δ^{13}C-C1 as a proxy for fluid maturity



Variation of δ^{13}C-C1 along pathways of the carbon cycle



Typical variation of δ^{13}C-C1 during the burial process

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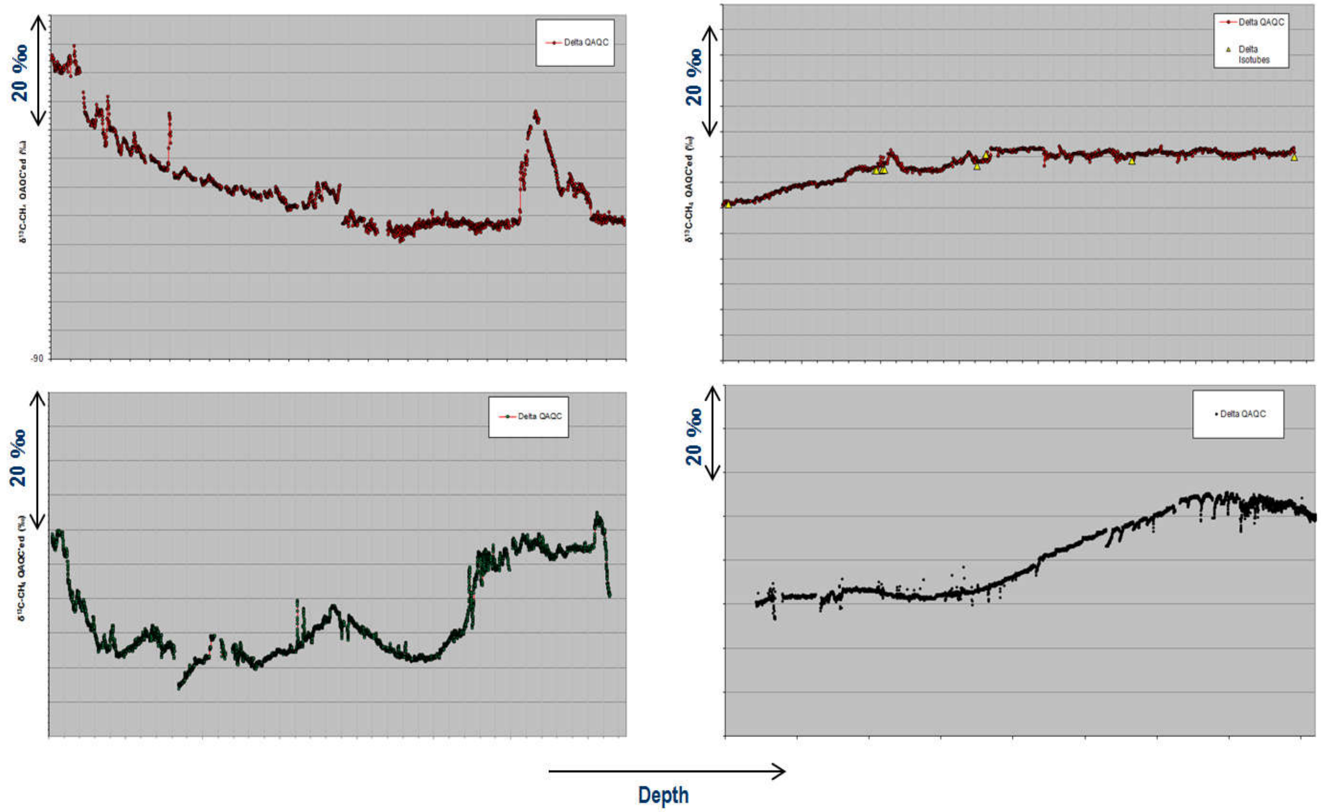
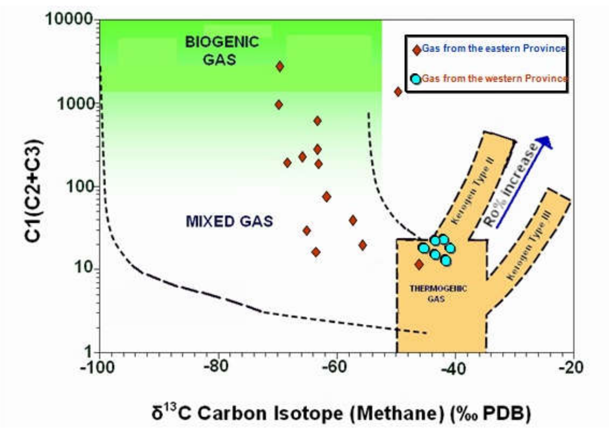
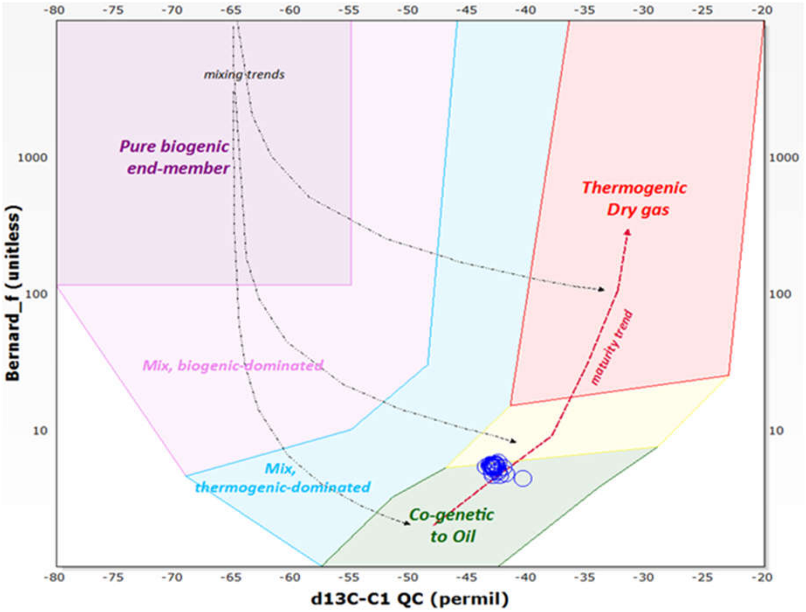
Methane isotope logging trends



Modified Bernard Plot





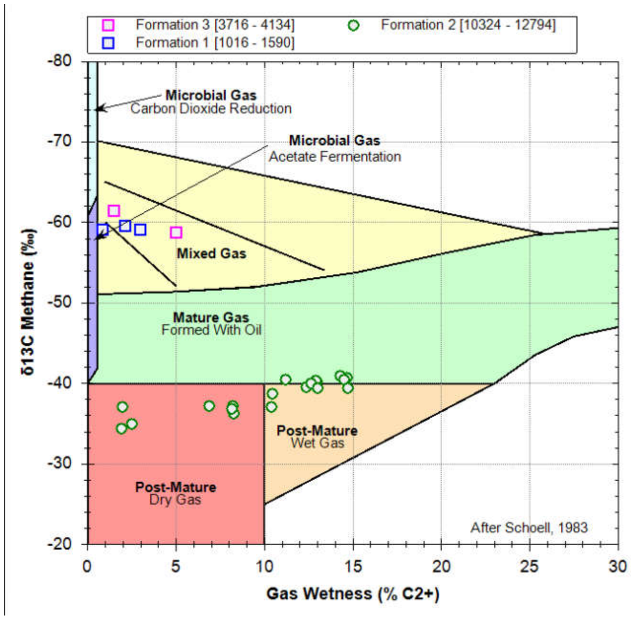
Basic Bernard plot

- Delineate biogenic and thermogenic gas
- Indication of mixing
- Indication of maturity

Modified Bernard plot:

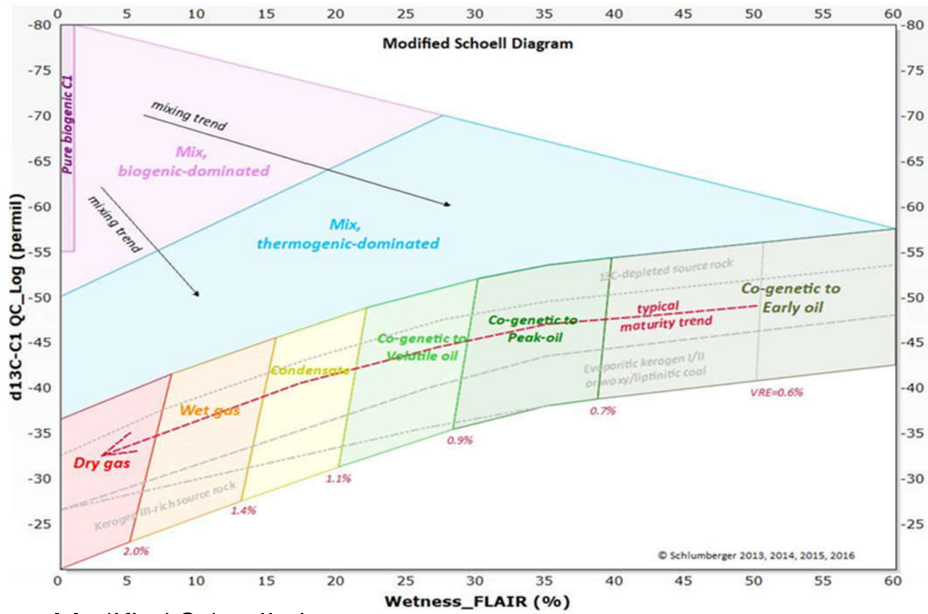
- Providing basic fluid association of methane and isotope trends using quantitative C1-C3

Modified Schoell Plot



Schoell plot

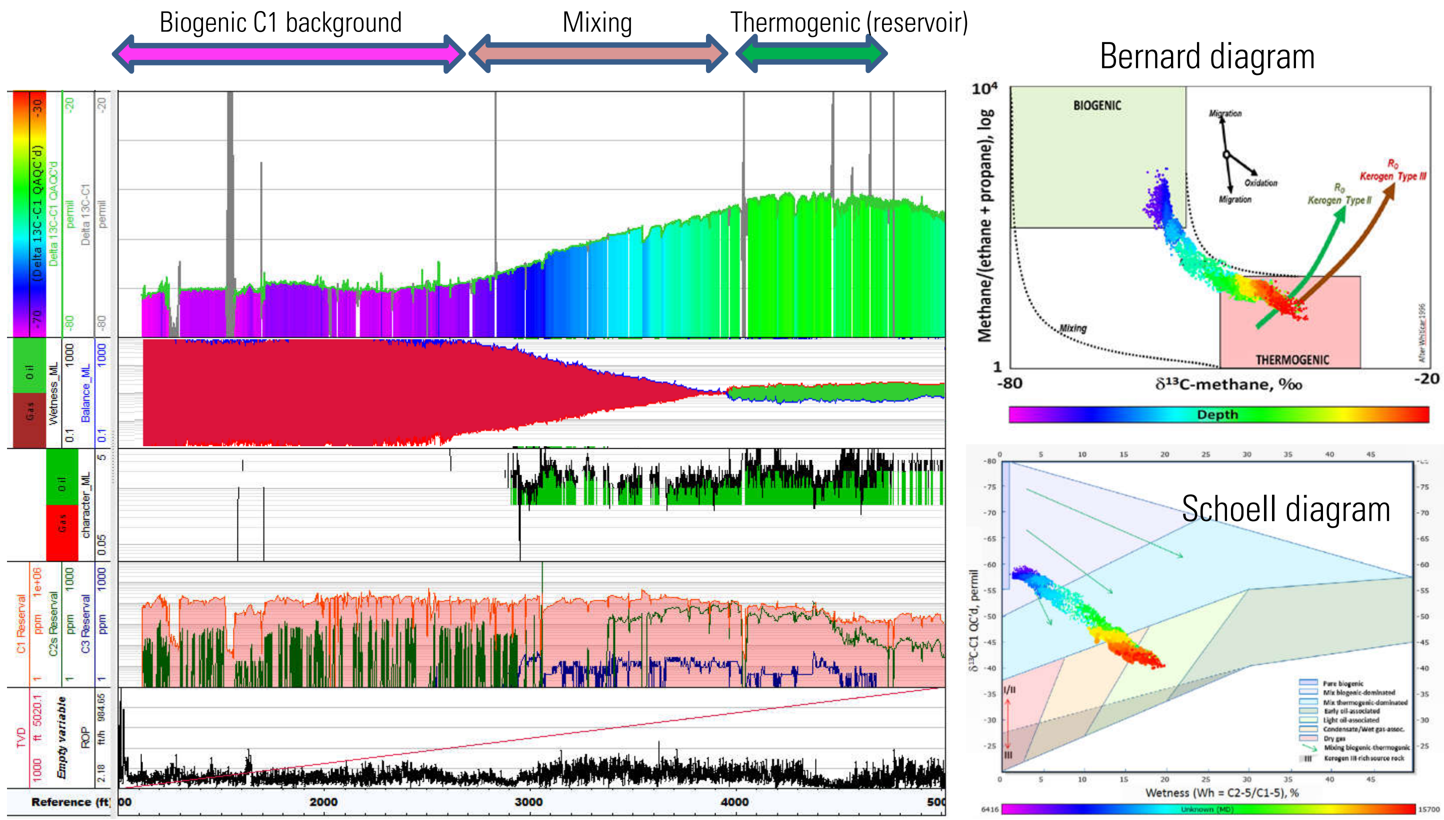
- Delineate biogenic and thermogenic gas
- Indication of mixing, maturity and gas association with fluids



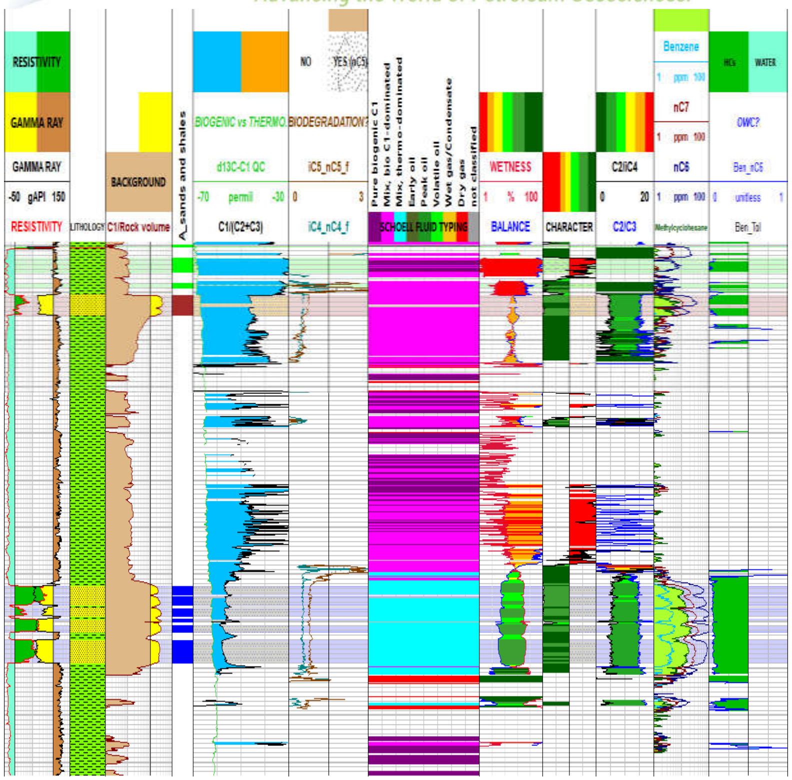
Modified Schoell plot:

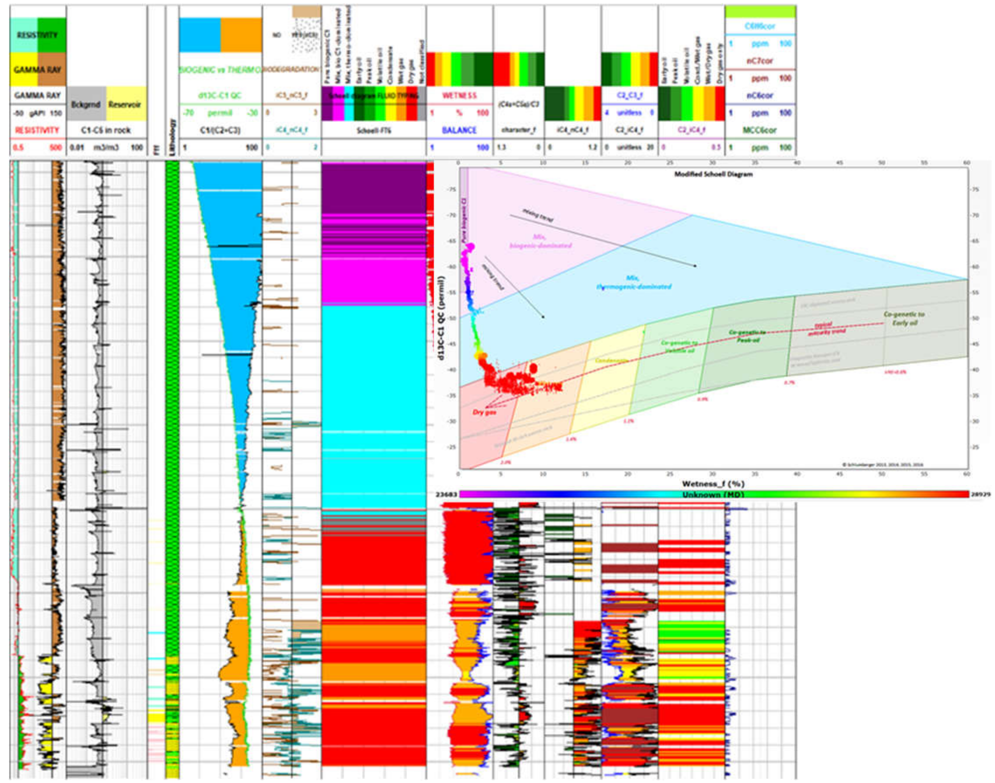
- Developed internally by SLB
- Fluid association of methane and isotope trends using Quantitative C1-C5
- Vitrinite reflectance equivalence scale for non-altered fluids

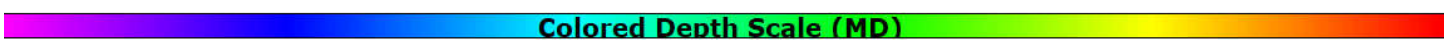
Mixing trend – active hydrocarbon system detection: simple mixing trend between the two end-members



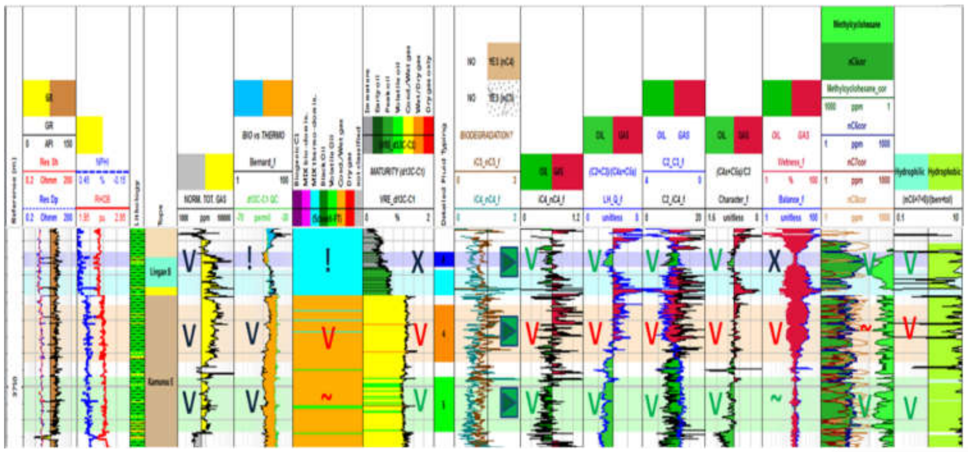
Interpretation of HC-Prone Intervals







Workflows: C1 isotope log + AMGL



HC-rich zone

Biogenic C1 Contribution?

YES

Thermogenic component biodegraded?

YES

- C6+ presence[&]

* In severe cases (biodegradation level >4 PM – Peters-Moldovan scale, even C2 and iC4 will be biodegraded, and C2/iC4 ratio affected
[&] n-alkanes will be likely affected too; still methylcyclohexane as more resistant might be indicative

NO

- OIL/GAS tracks
  - iC4/nC4
  - Character
  - LH_Q
  - C2/C3 vs C2/iC4
- C6+ presence

NO

- OIL/GAS tracks[#]
  - iC4/nC4
  - Wh vs Bh
  - Character
  - LH_Q
  - C2/C3 vs C2/iC4
- C6+ presence
- MATURITY (δ^{13}C-C1)
- Schoell-FT co-genetic fluid typing

[#] Check consistency of Oil vs Gas indications: Higher i/n and d13C-C1 can be also due to kerogen III contribution to the source rock of this fluid = kerogen III present in SR

Key Message

Conclusions

- Mud-gas composition represents reservoir rock-contained fluid composition
  - Appropriate correction make mud-gas immune to drilling and rig conditions
- Interpretation
  - Addition of critical parameters: mud-gas isotopes and C6+ isomers
  - Continuity of data helps understand seals, contacts and transition zones
- Delivering key information on time
  - Fluid abundance, fluid types, fluid alterations
  - High-frequency distribution of the above

Acknowledgements

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- Adil Ceyhan Gurkan (Schlumberger)
- Mostafa Hassan Al Daboos (Schlumberger)