Archie's Law - Boon or Bane?
An approach to estimate gas hydrate saturations

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Theory → Instrumentation → Field Study Data → Processing → Modeling / Inversion → Resistivity Model → Geological Interpretation

Archie's Law (1942)

$$\boxed{\rho_{f'} = a\,\rho_w\,\Phi^{-m}\,(1-S_h)^{-n}}$$

Empirical / Petrophysical Model

The Boon: A practical tool to relate resistivity to porosity, salinity, saturation estimates

The Bane: Often used standard coefficients may lead to over- / underestimated saturation estimates

EMTF 2019 Haltern, K. Schwalenberg, Archie's Law

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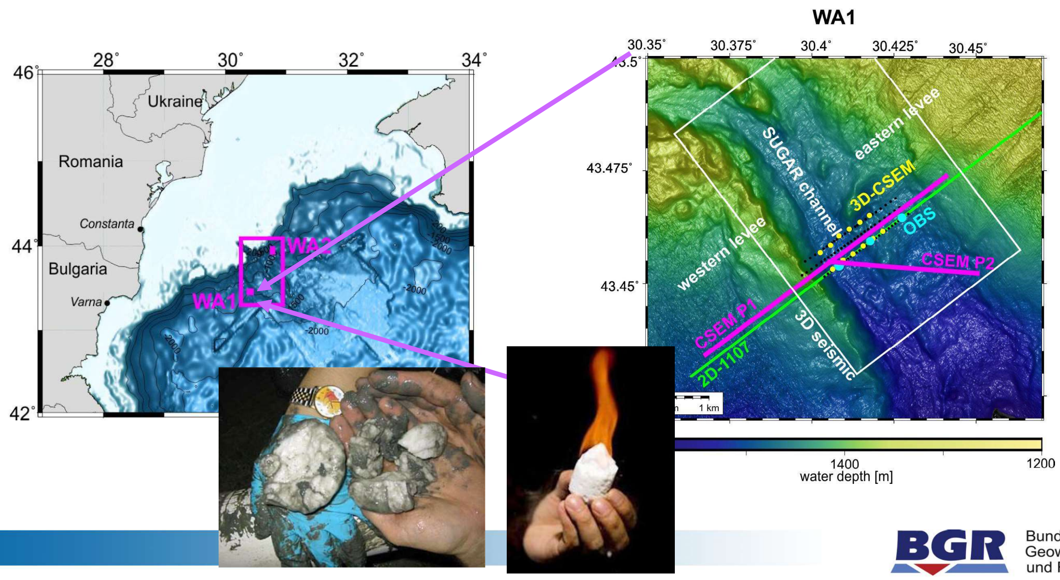
Daube Delta, Western Black Sea



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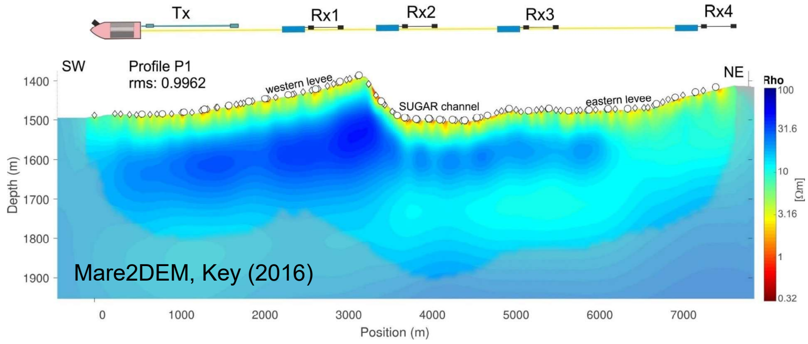
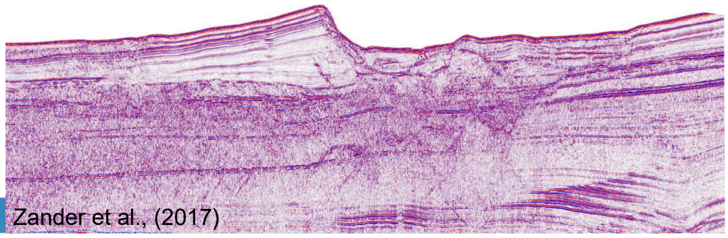
Resistivity model, Gas Hydrates, Black Sea





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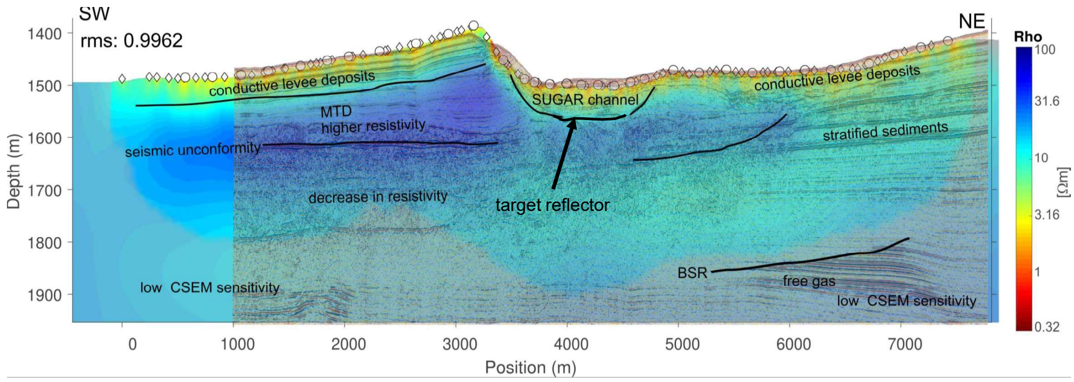
Resistivity Model, Gas Hydrates, Black Sea

what is the gas hydrate saturation?



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Archie's Law, parameters

$$\rho_f = a\,\rho_w\,\Phi^{-m}$$

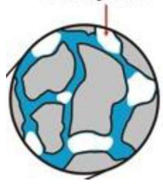
$$\rho_{f'} = a\,\rho_w\,\Phi^{-m}\,(1-S_h)^{-n}$$

$$\rho_{f'} = \rho_f\,(1-S_h)^{-n}$$

$$\frac{1}{R} = \frac{\phi^m}{aR_w(1-V_{cl})}S_w^n + \frac{V_{cl}}{R_{cl}}S_w^{n-1}.$$

ρ_f = formation resistivity
a = constant, tortuosity factor
ρ_w = pore water resistivity
Φ = porosity
m = cementation factor

S_h = gas hydrate saturation
n = saturation exponent
ρ_f / ρ_w = formation factor



R_{cl} = clay resistivity
V_{cl} = clay volume fraction

Simandoux, 1963, Lee & Collett, 2006

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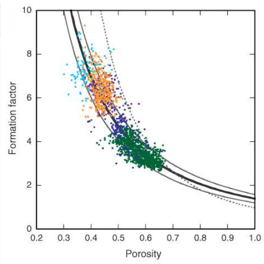
Archie coefficients :

a	1 for Φ =100% ≠ 1 Intercept of the log ρ / log Φ at Φ=100%	Winsauer 1952	Better fit
m	1.8 - 2.0 unconsolidated sands 1.4 - 1.9 sand to shell 2.0 - 2.3 clean sands 1.8 - 3.0 compacted sandstone 1.945	Archie, 1942 Jackson et al, 1978 Salem & Chilingariam, 1999 Riedel et al., 2019	Depends on shape rather than grain size and sorting; Varies with clay content
n	~ 2 1.9386 0.5 - 4 2.5 +/- 0.5	Archie, 1942 Pearson et al, 1983 Spangenberg 2001 Cook& Waite, 2018	Depends on m, Φ, grain size and distribution, saturation



m: slope
a: intercept at Φ = 100%

a = 1, m = 2, n = 2 are often used standard Archie coefficients

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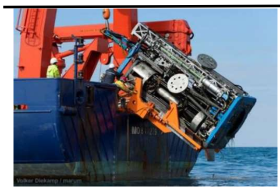
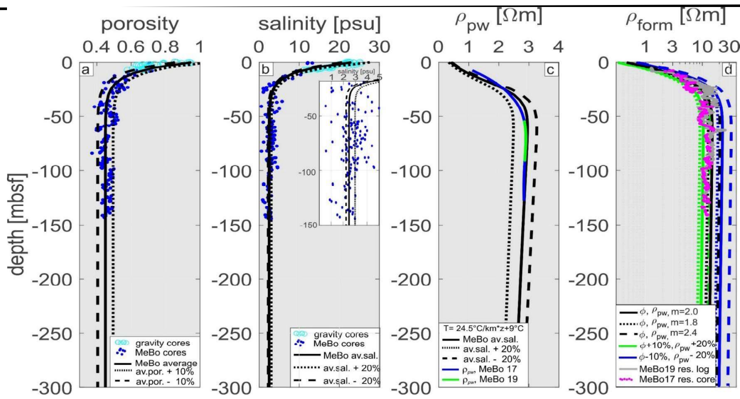
MeBo Drilling:



$$\rho_f = a\, \rho_w\, \Phi^{-m}$$

a = 0.988, m = 1.945
Riedel et al., 2019



- **porosity decrease** from ~70% at seafloor to ~45% below 30m
- **salinity decrease** from 22 psu at seafloor to 2.5 (*4.0, Popescu et al., 2006*) psu below 30m
- **pore water resistivity increase** to 2.86 Ωm (2.5 psu) below 30m (Fofonoff, 1983)

→ **MeBo res. log** is within the range of derived background resistivities

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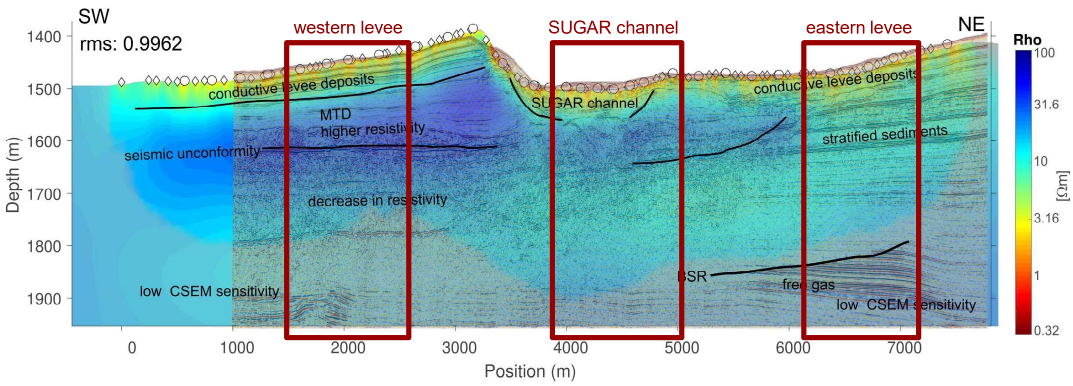
Model selection:



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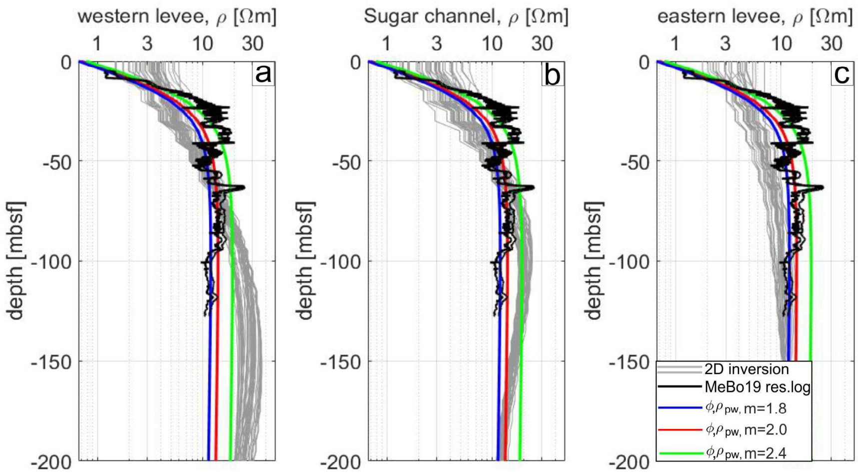
MeBo resistivity compared to inverted resistivity:



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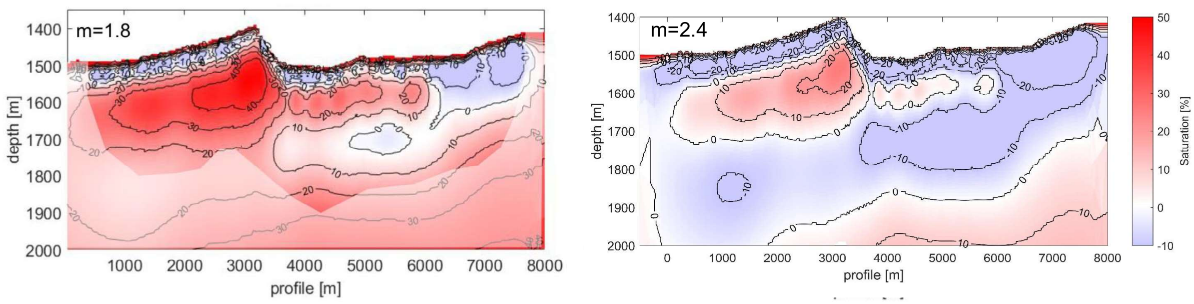
Saturation Models



- Average porosity: 75 % → 45% below 40 m
- Average pore water resistivity: 0.4 Ωm → 2.86 Ωm below 40 m
- a=1 , n=2.5

Does the same set of Archie coefficients hold for the entire model?

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Stochastic Approach, 1D

Input parameter ranges:

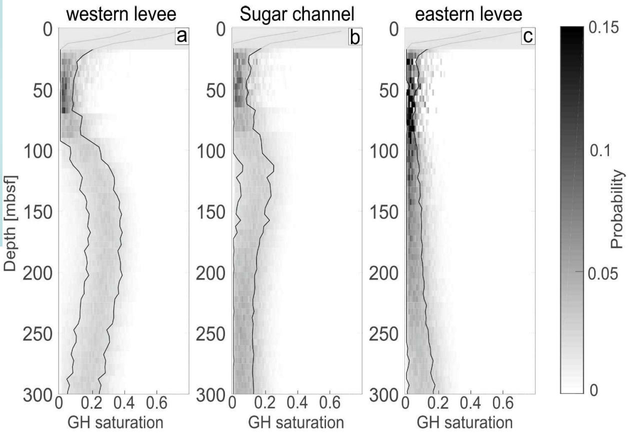
- Log ρ ranges (Gaussian)
- Average porosity +/- 20% (Gaussian)
- Average pore water resistivity, salinity +/- 10% (uniform)
- a = [0.9 1.1]; m = [1.8 2.5]; n = [2.0 2.5] (uniform)

→ **5000 realizations of Archie's Law**

→ **sorting (rms < 1), GH binning [0 1]**

$$\boxed{S_h = 1 - \left[{a\, \rho_w\, \phi^{-m}} / {\rho_f} \right]^{1/n}}$$

After Sava and Hardage, 2007



68% confidence intervals

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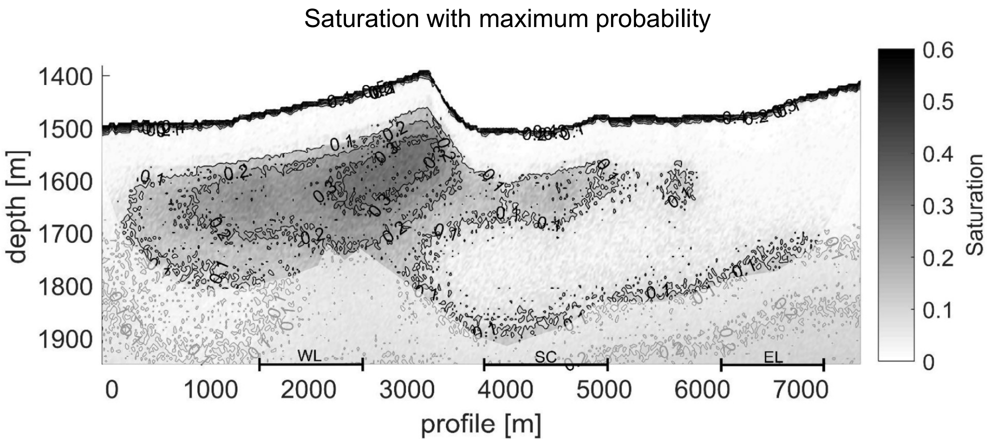
Stochastic Approach, 2D



Schwalenberg et al., soon submitted to SI MarPotGeo

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Conclusions

Archie's Law (1942)

$$\boxed{\rho_{f'} = a\ \rho_w\ \Phi^{-m}\ (1\text{-}S_h)^{-n}}$$

- **The Boon: A practical tool to relate resistivity to porosity, salinity, saturation estimates**
- **The Bane: Often used standard coefficients may lead to over- / underestimated saturation estimates**
- **The stochastic approach can help to define saturation ranges based on probability and credibility intervals**

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