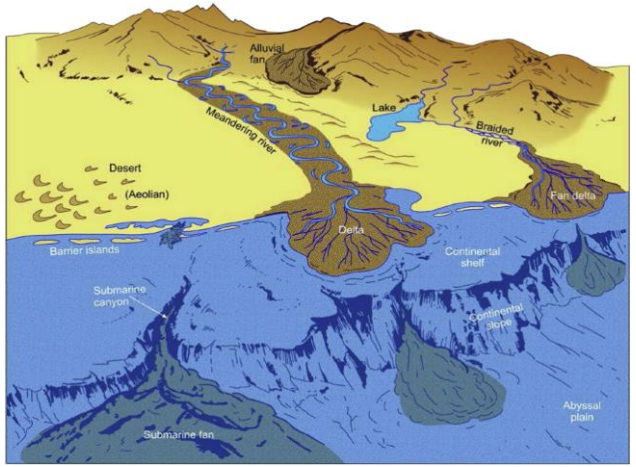
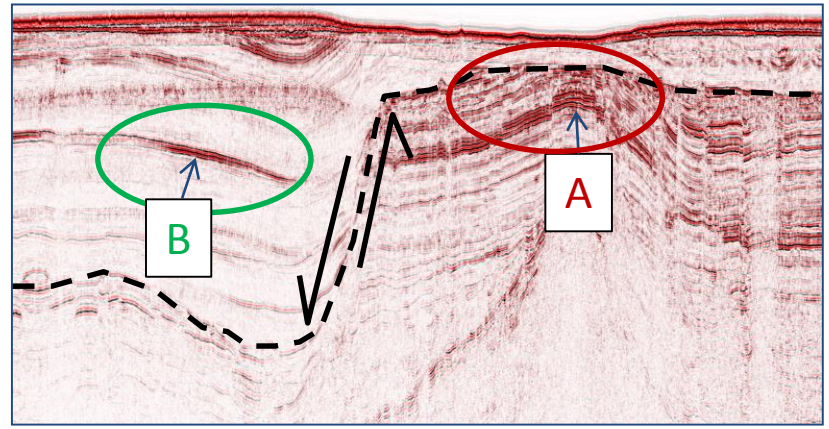
From loose grains to stiff rocks – The rock-physics "life story" of a clastic sediment, and its significance in QI studies

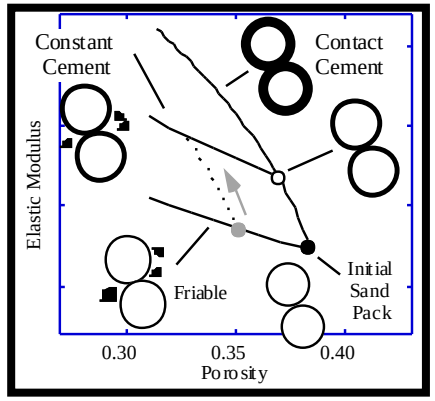
Prof. Per Avseth, NTNU/G&G Resources

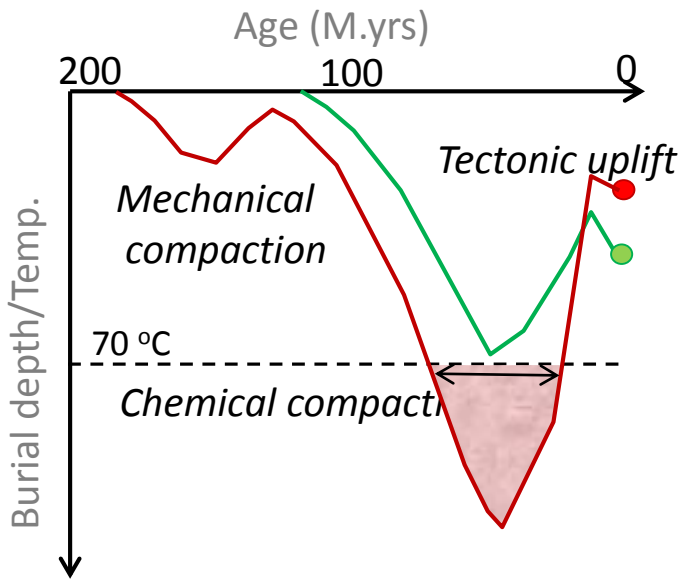
The rock physics "life story" of a clastic sediment – a teaser:



Bjørlykke (2015)

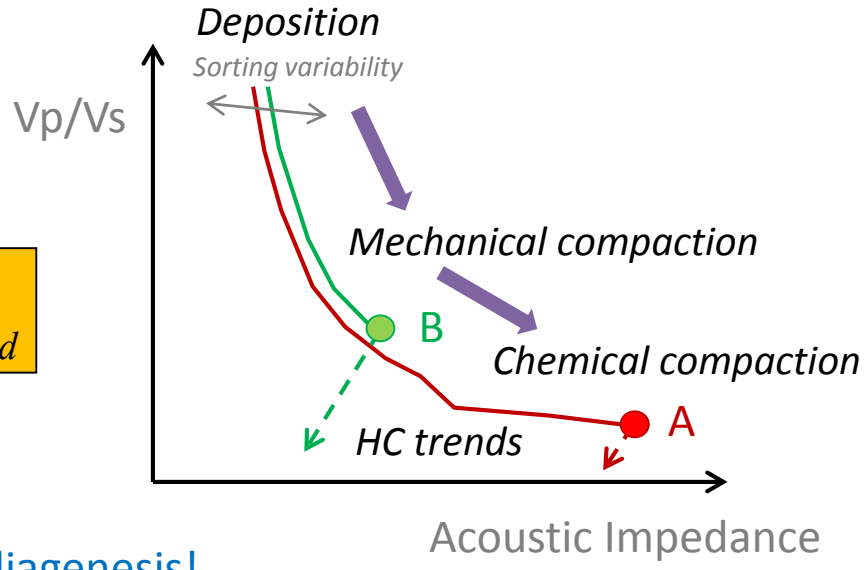






$$\frac{1}{K_{sat}} \approx \frac{1}{K_{mineral}} + \frac{\phi}{K_{\phi} + K_{fluid}}$$

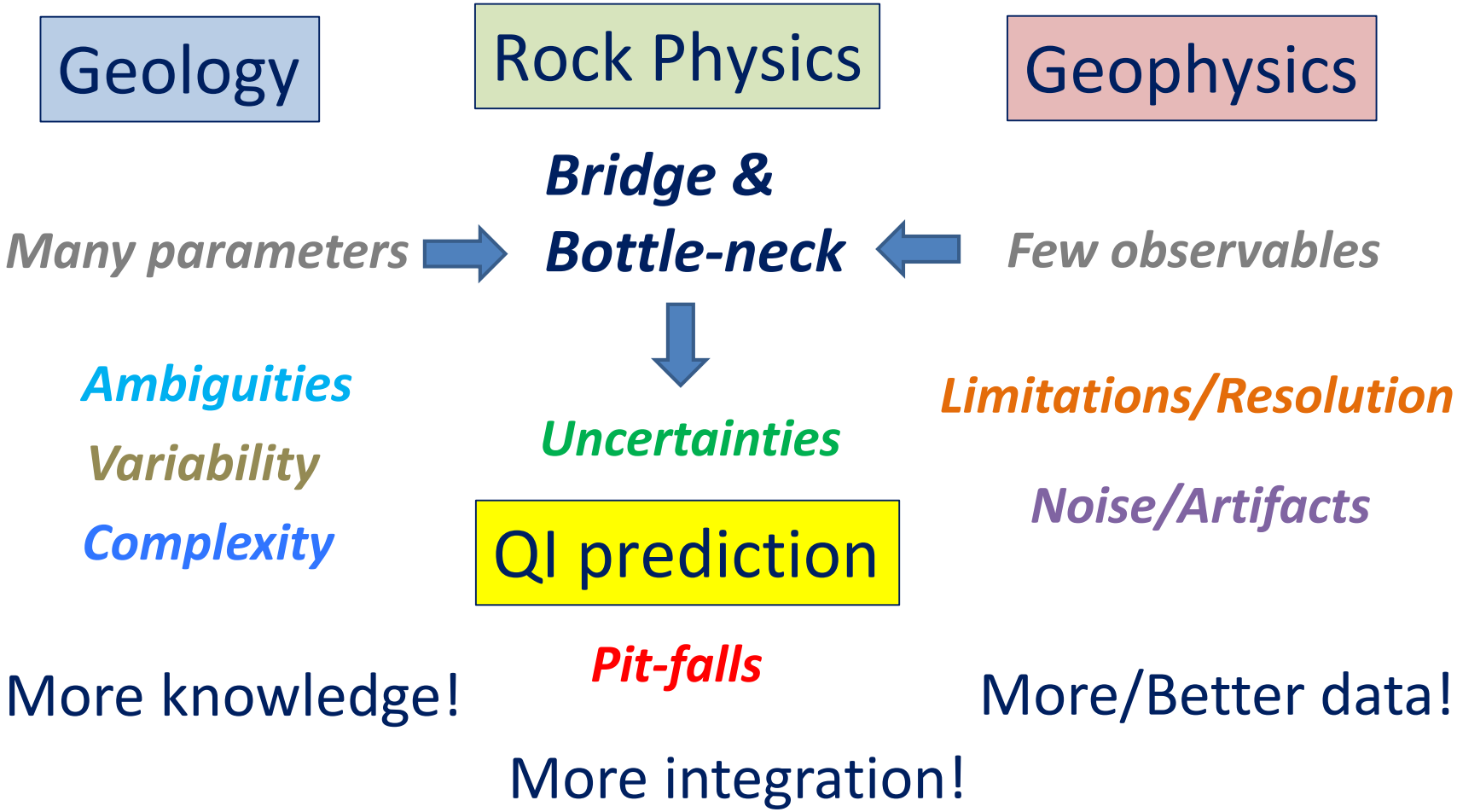
Pore compressibility strongly affected by diagenesis!



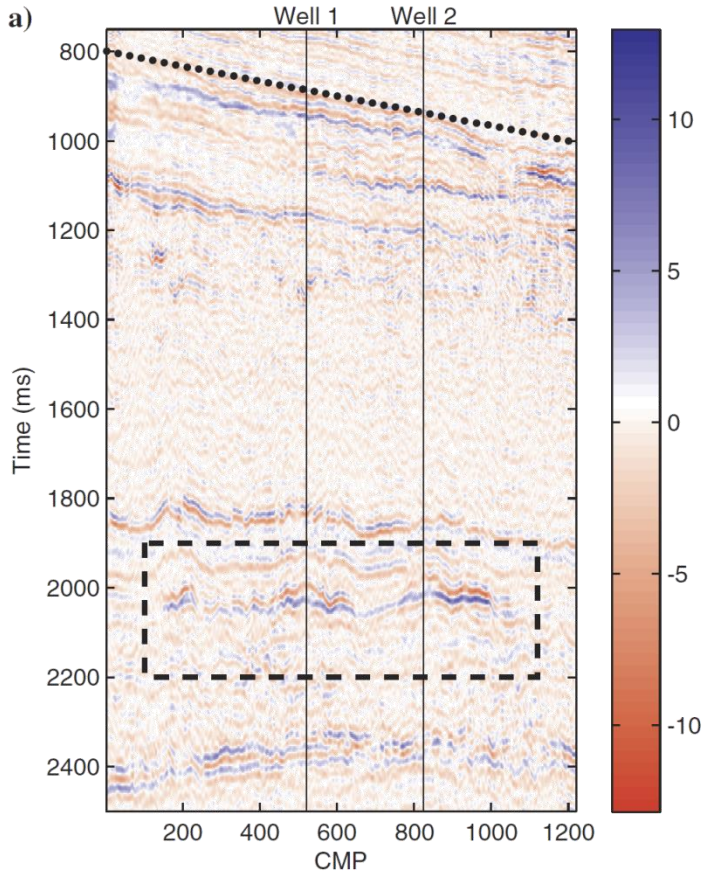
Selected references:

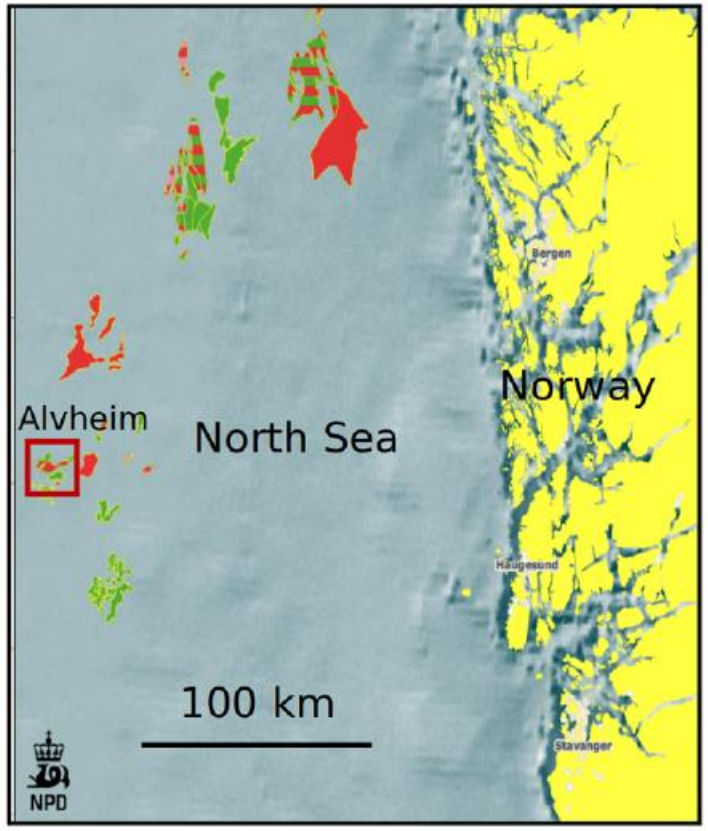
- Helset et al., 2004: Combined diagenetic and rock physics modeling for improved control on seismic depth trends (EAGE Abstract)
- Brevik et al., 2011: Rock Physicist step out of the well location, meet geophysicists and geologists to add value in exploration analysis (The Leading Edge).
- Dræge et al. 2014: Linking rock physics and basin history – Filling gaps between wells in frontier basins (The Leading Edge).
- Zadeh et al. 2016: Compaction and rock properties of Mesozoic and Cenozoic mudstones and shales, northern North Sea (Marine and Petroleum Geology).
- Avseth and Lehocki, 2016: Combining burial history and rock-physics modeling to constrain AVO analysis during exploration (The Leading Edge).

Reducing uncertainties through integration

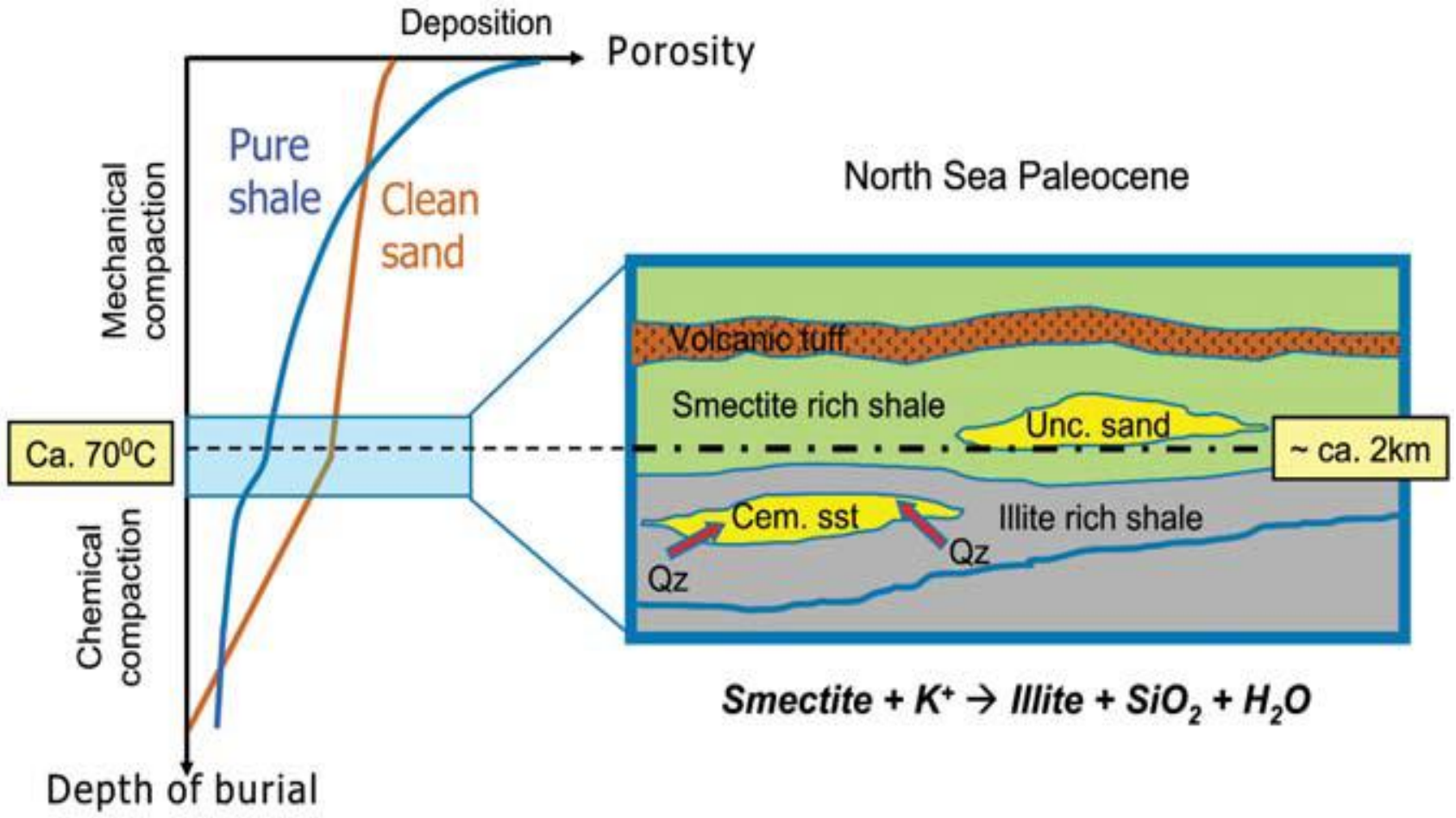


Case example from North Sea (Alvheim Field)

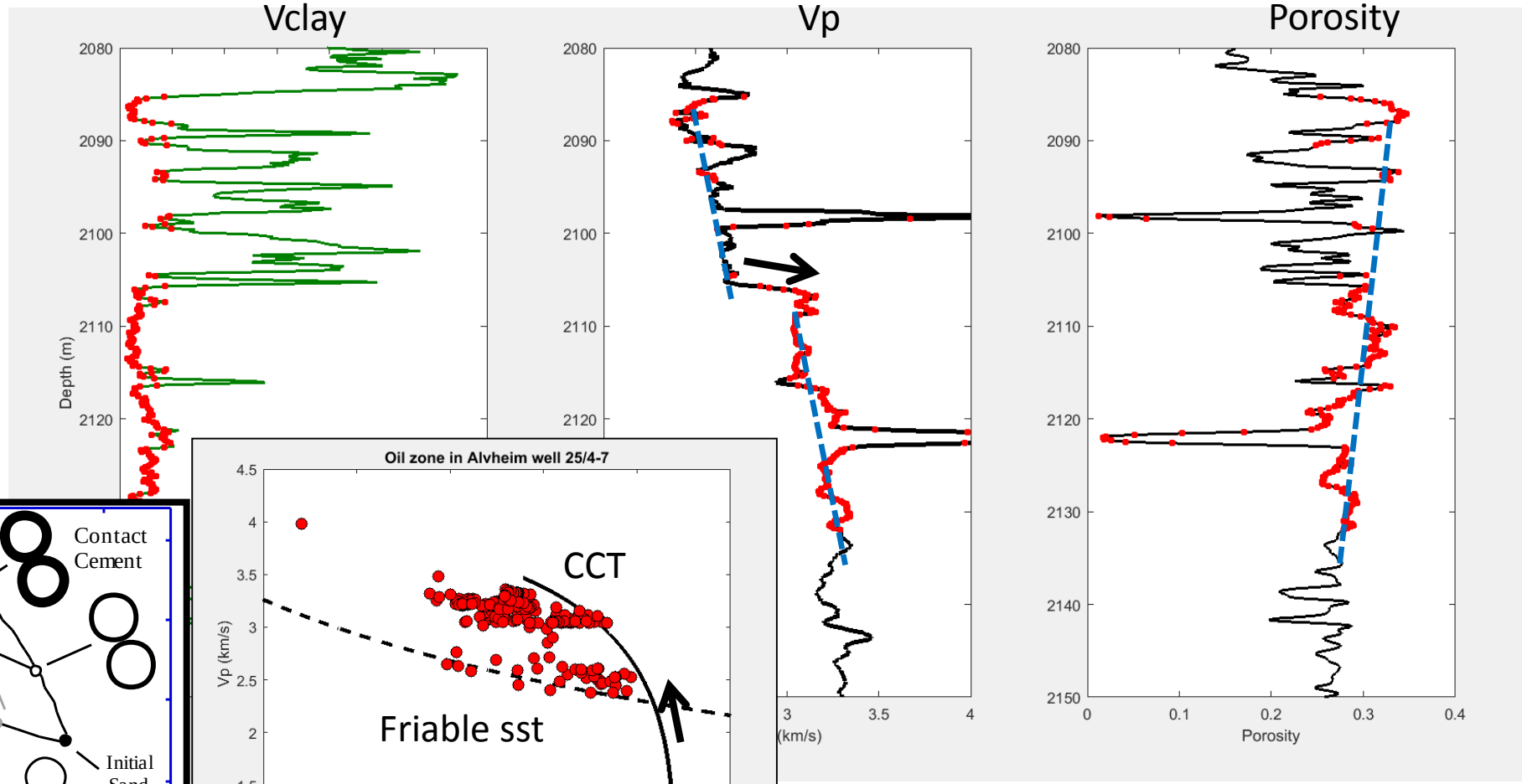




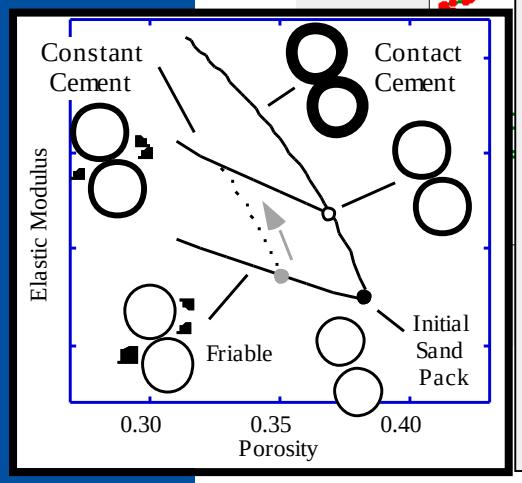
Sand and shale compaction trends in the North Sea



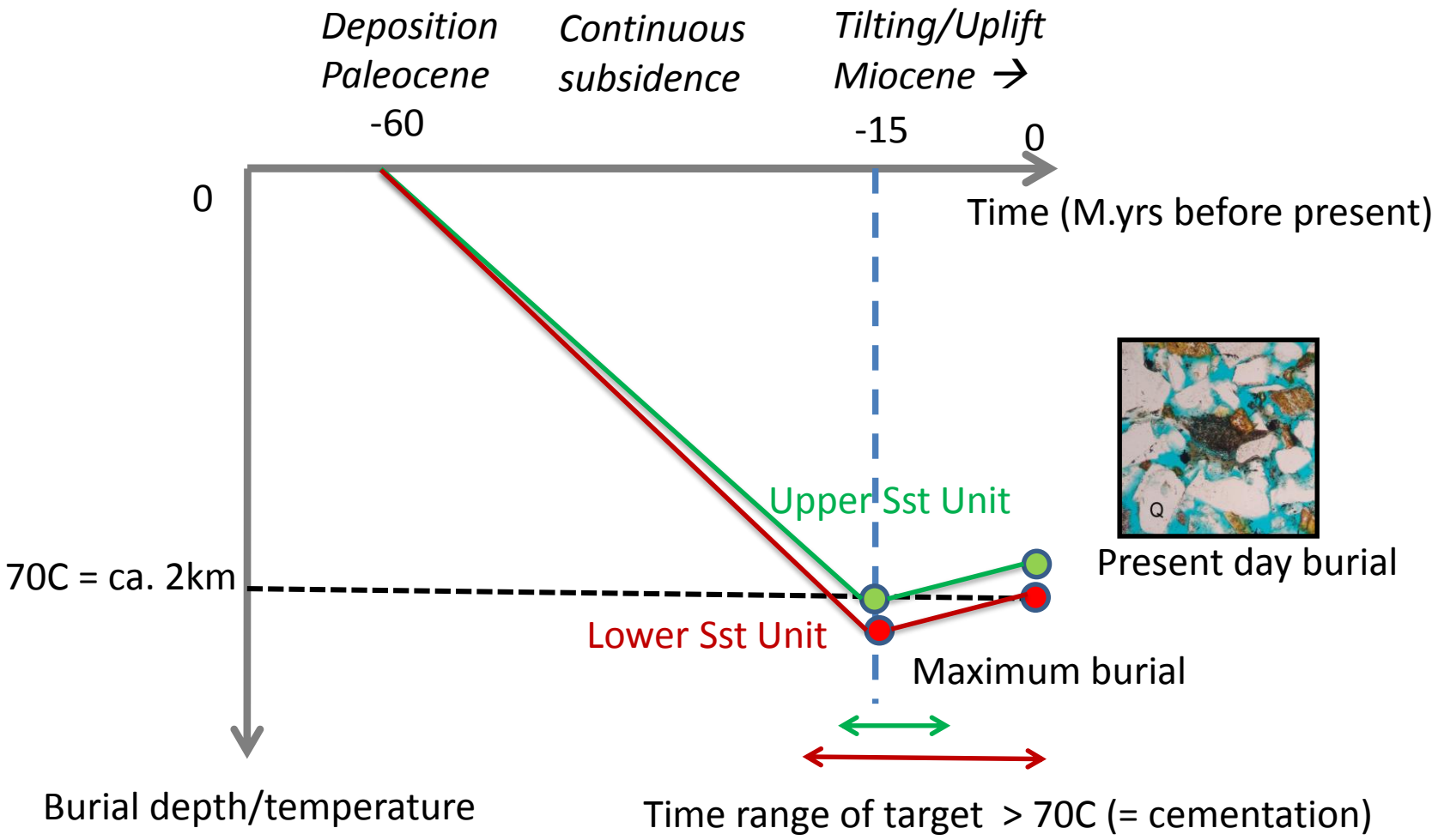
Alvheim well (Kneler discovery)
Velocity jump in sst due to cementation



Oil leg

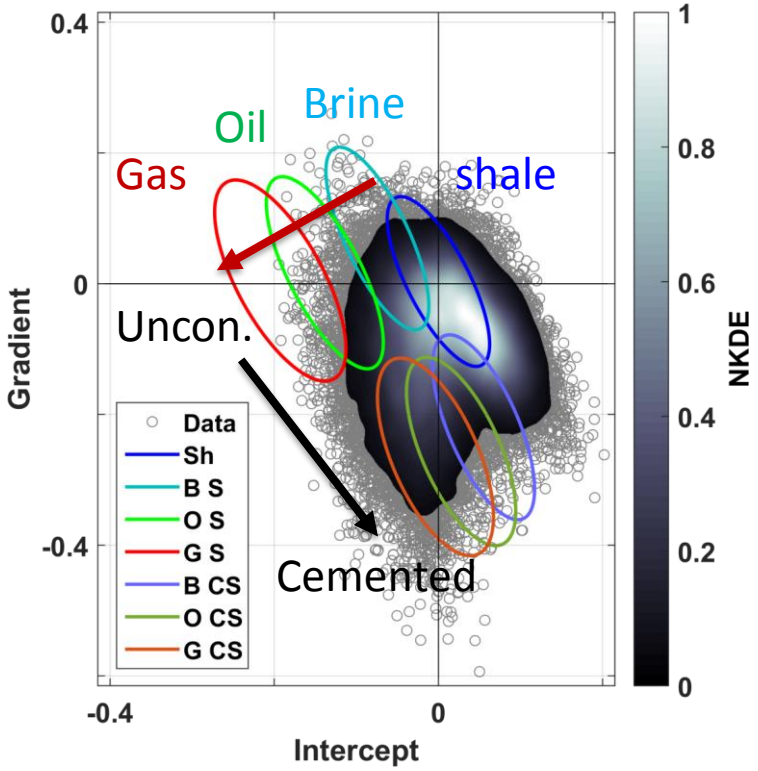


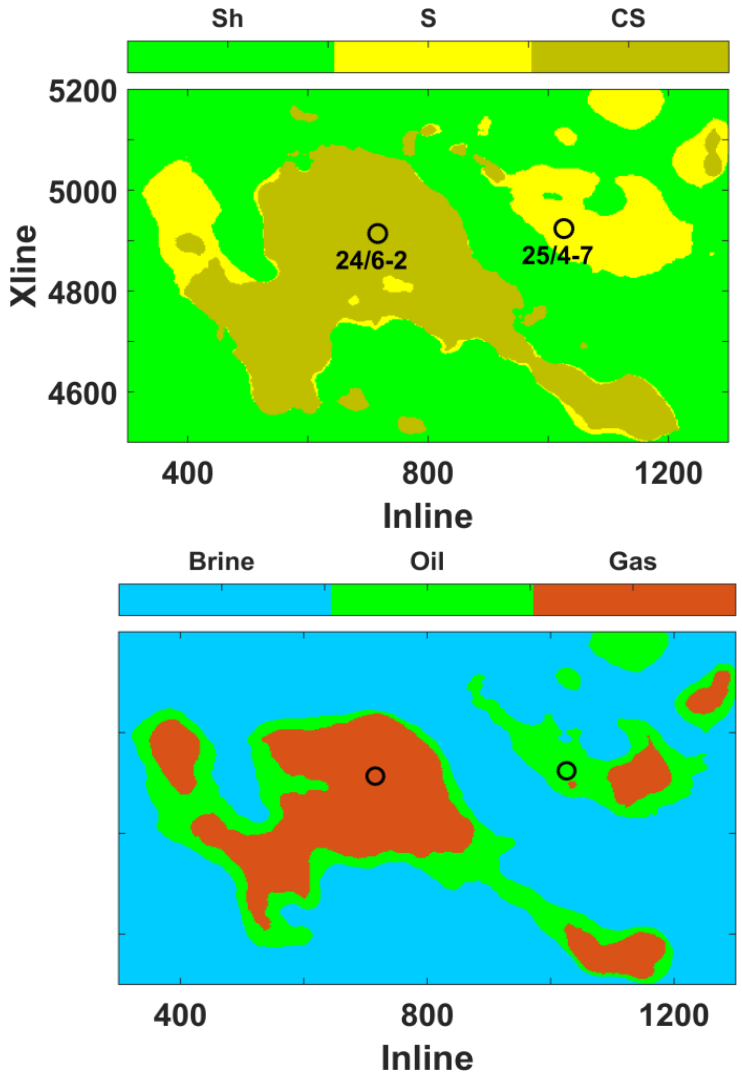
Burial history and subsidence curves for top reservoir sst at Kneler well (schematic)



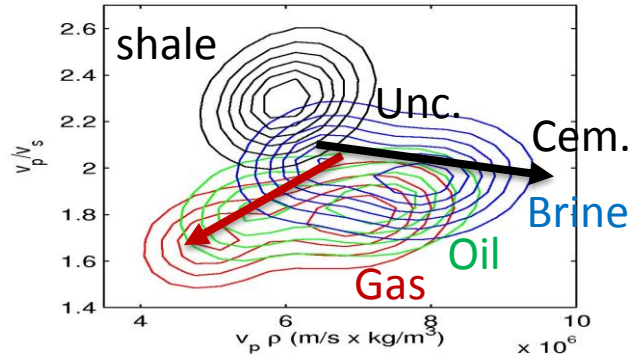
AVO classification constrained by depth trends (Alvheim field, North Sea)

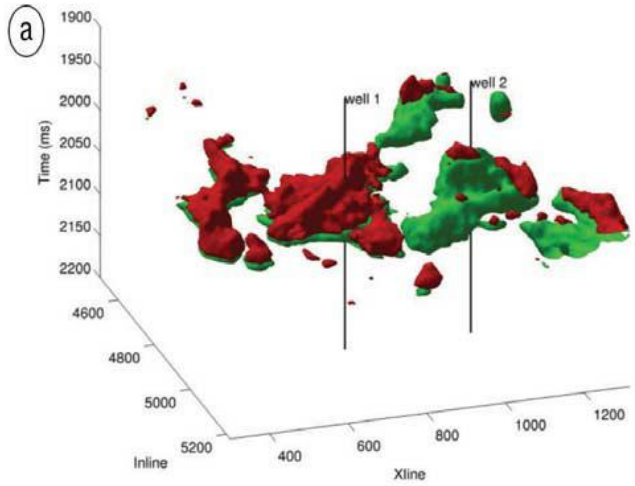
Avseth and Lehocki (2016)
(Mahalanobis distance)



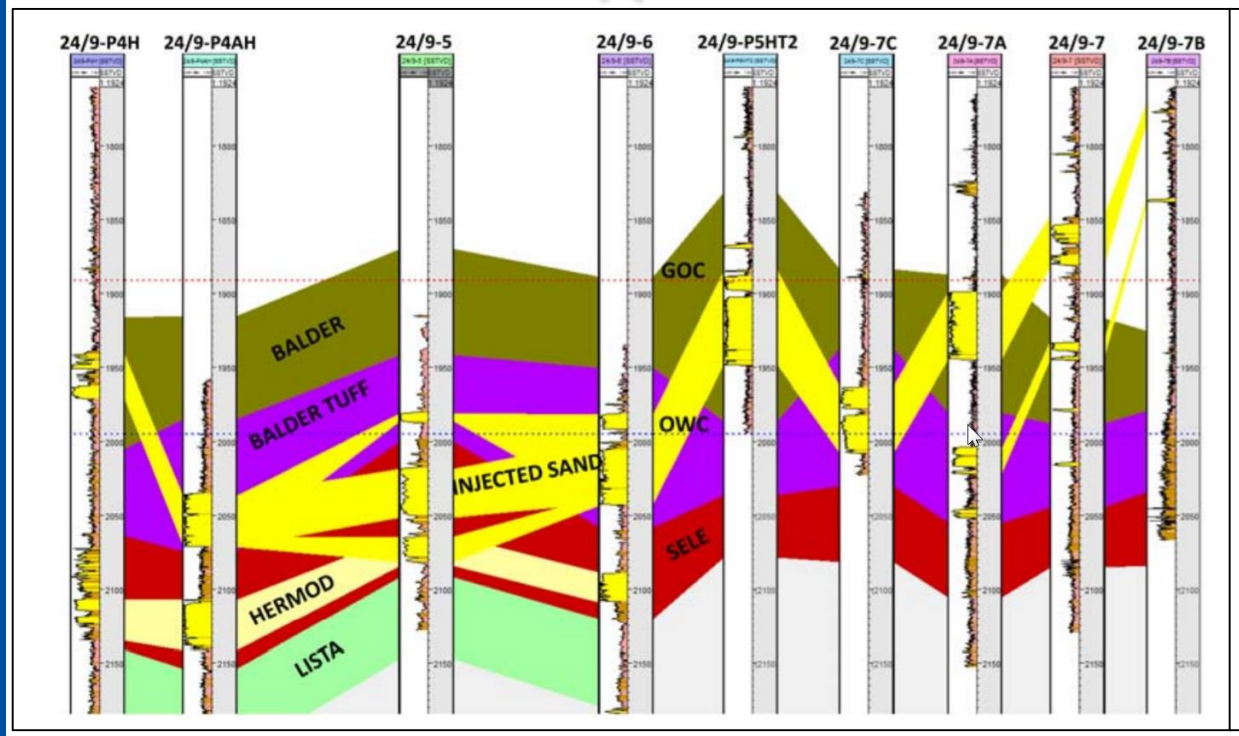


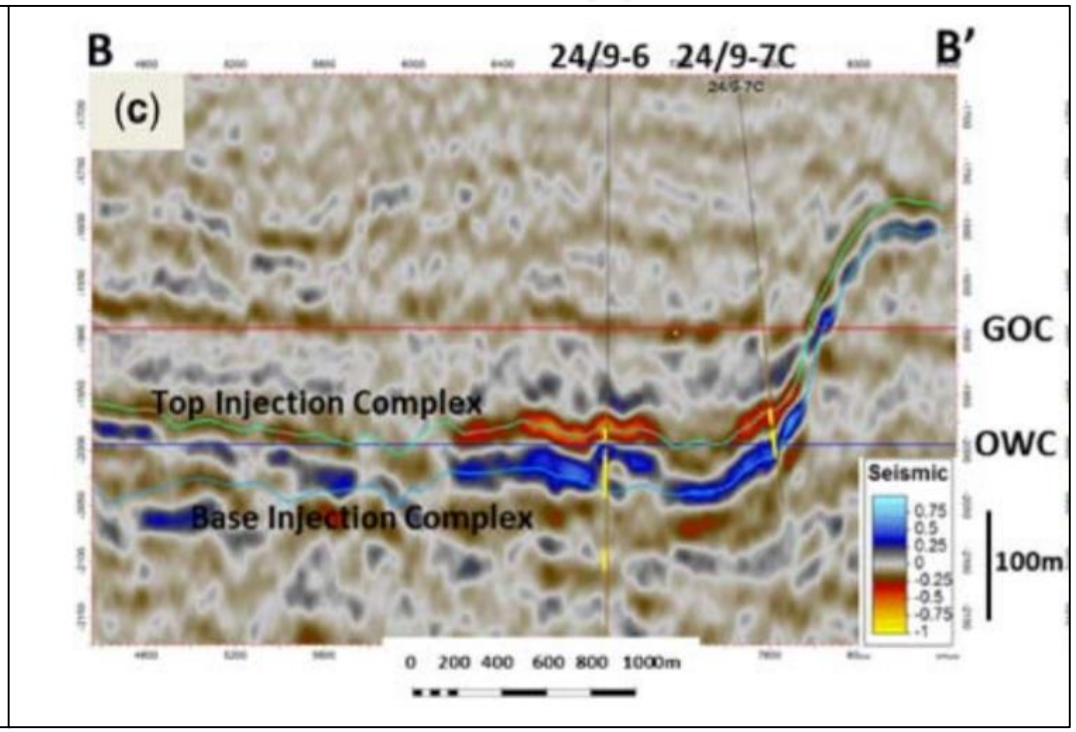
Rimstad et al. (2012):
(Bayesian classification)





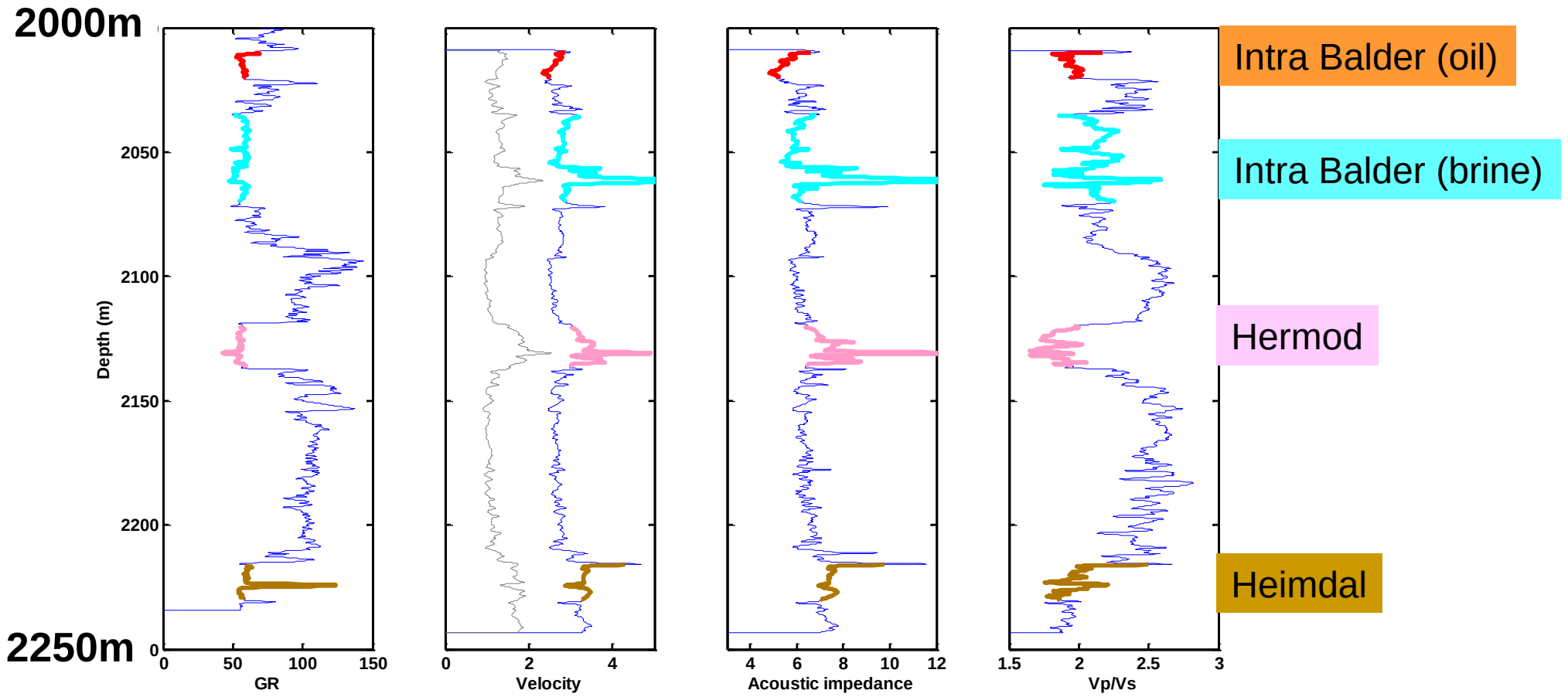
Are injectites on Volund cemented or not?





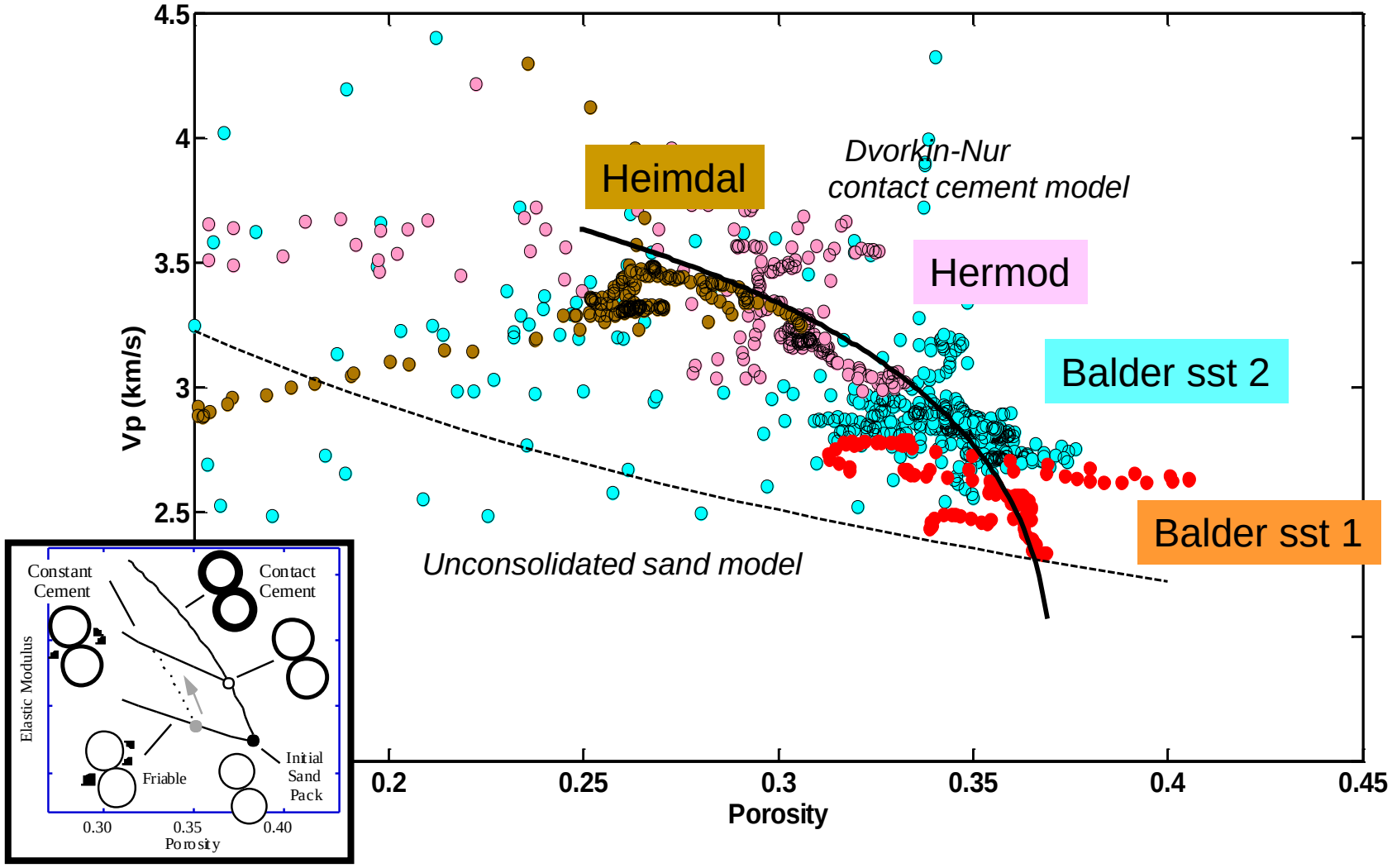
From Schwab et al. 2015

Well log data from 24/9-6



GR Vs & Vp AI Vp/Vs

Rock Physics diagnostics of Paleocene sandstone units



Combined modeling of burial history and rock physics

Mechanical compaction (Lander and Walderhaug, 1999)

Sum of pore space: $IGV = IGV_f + (\varphi_0 + m_0 - IGV_f)e^{-\beta\sigma_{eff}}$

Stable packing configuration — IGV_f

Initial volume of pore filling material — m_0

Dep. porosity — φ_0

Effective stress — σ_{eff}

Exponential decline factor — β

Chemical compaction (Walderhaug, 1996), when T > 70 C

$$V_{q2} = \varphi_0 - (\varphi_0 - V_{q1})exp\frac{-MaA_0}{\rho\varphi_0 bc \times ln10}[10^{bT_2} - 10^{bT_1}]$$

Volume of Qz cement precipitated between time T1 and T2 — V_{q2}

Porosity at Cement start — φ_0

Volume of Qz cement at time T1 — V_{q1}

Molar weight of qz — M

Qz- precipitation rate — a

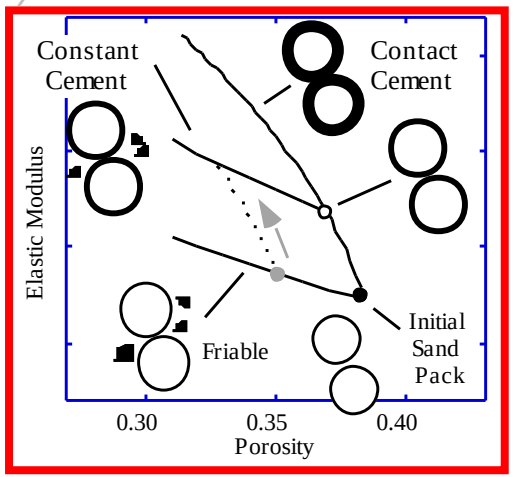
Qz- surface area — A_0

Qz- density — ρ

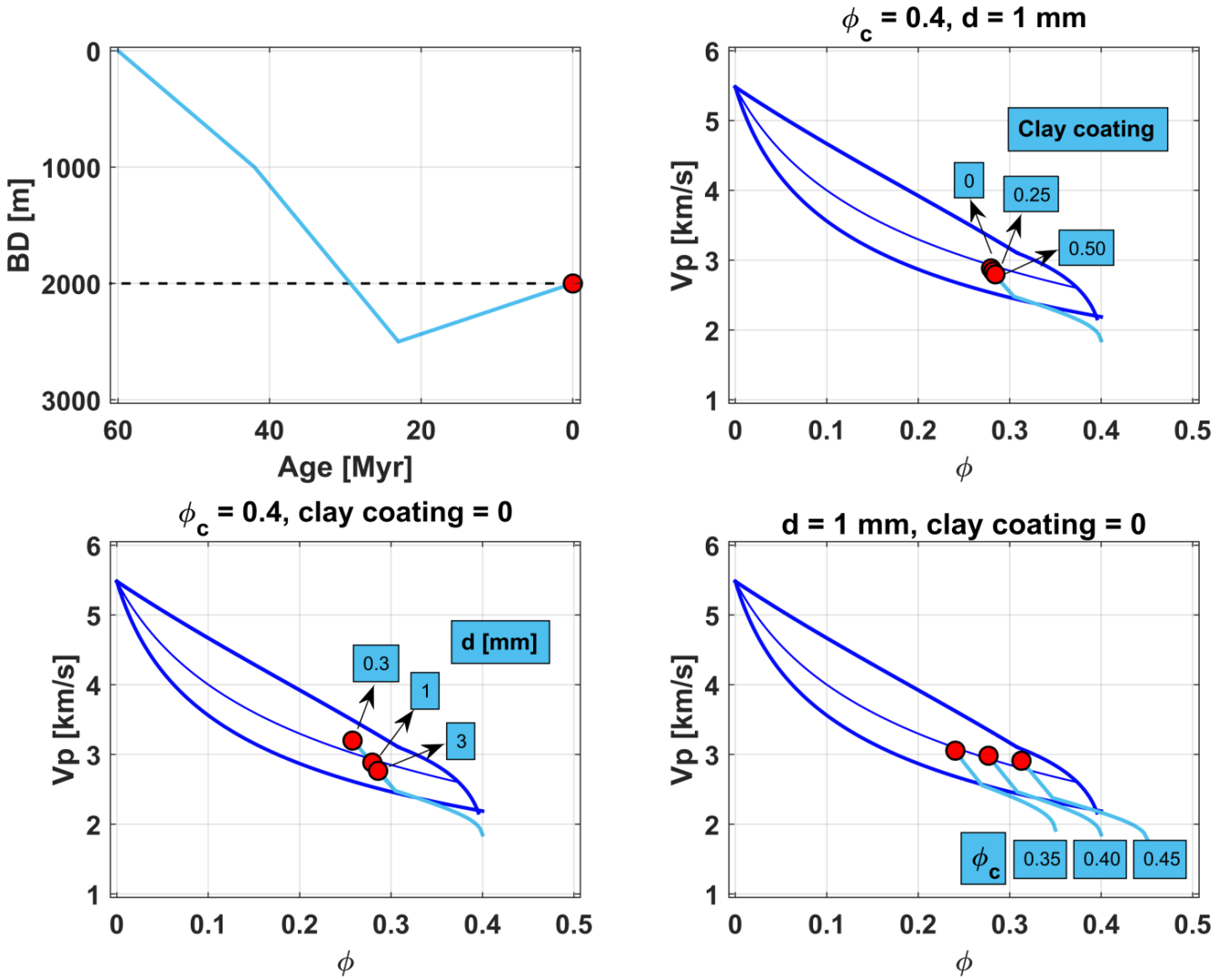
Heat rate — b

Rock physics modeling

Hertz-Mindlin (mech. comp)
Dvorkin-Nur + Hashin-Shtrikman (chemical compaction)



Combined burial and rock physics modeling of porosity versus P-wave velocity (sensitivity study)



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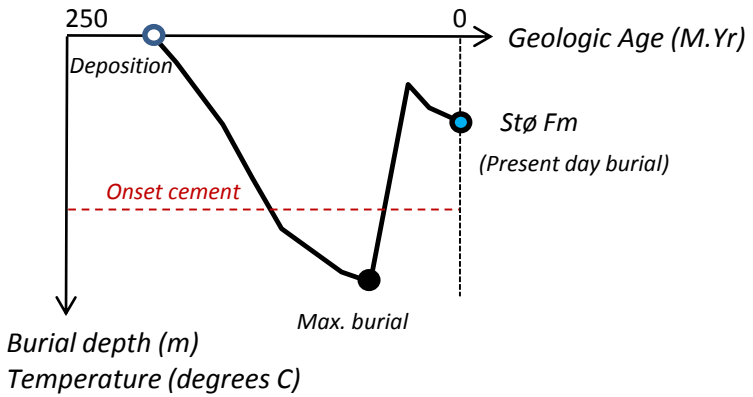
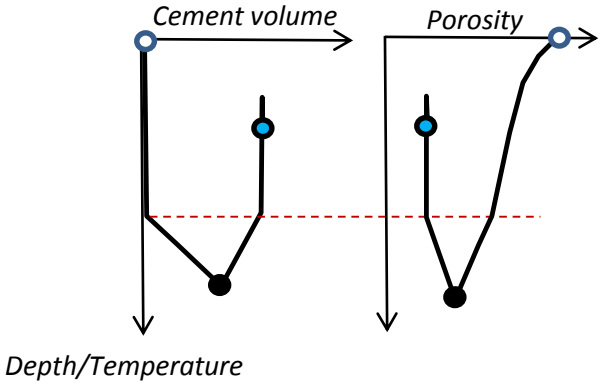
Rock physics and AVO modeling constrained by burial history

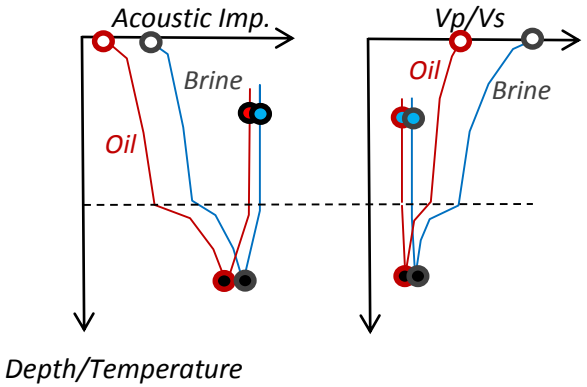
1. Burial history



2. Diagenetic modeling (Walderhaug)

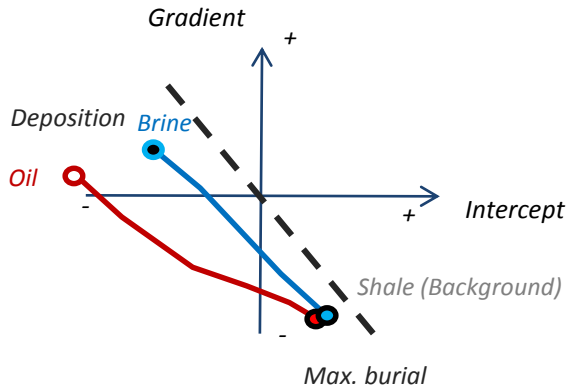


3. Rock physics modeling (Dvorkin-Nur)



+ shale compaction and RP

4. AVO modeling (Zoeppritz)



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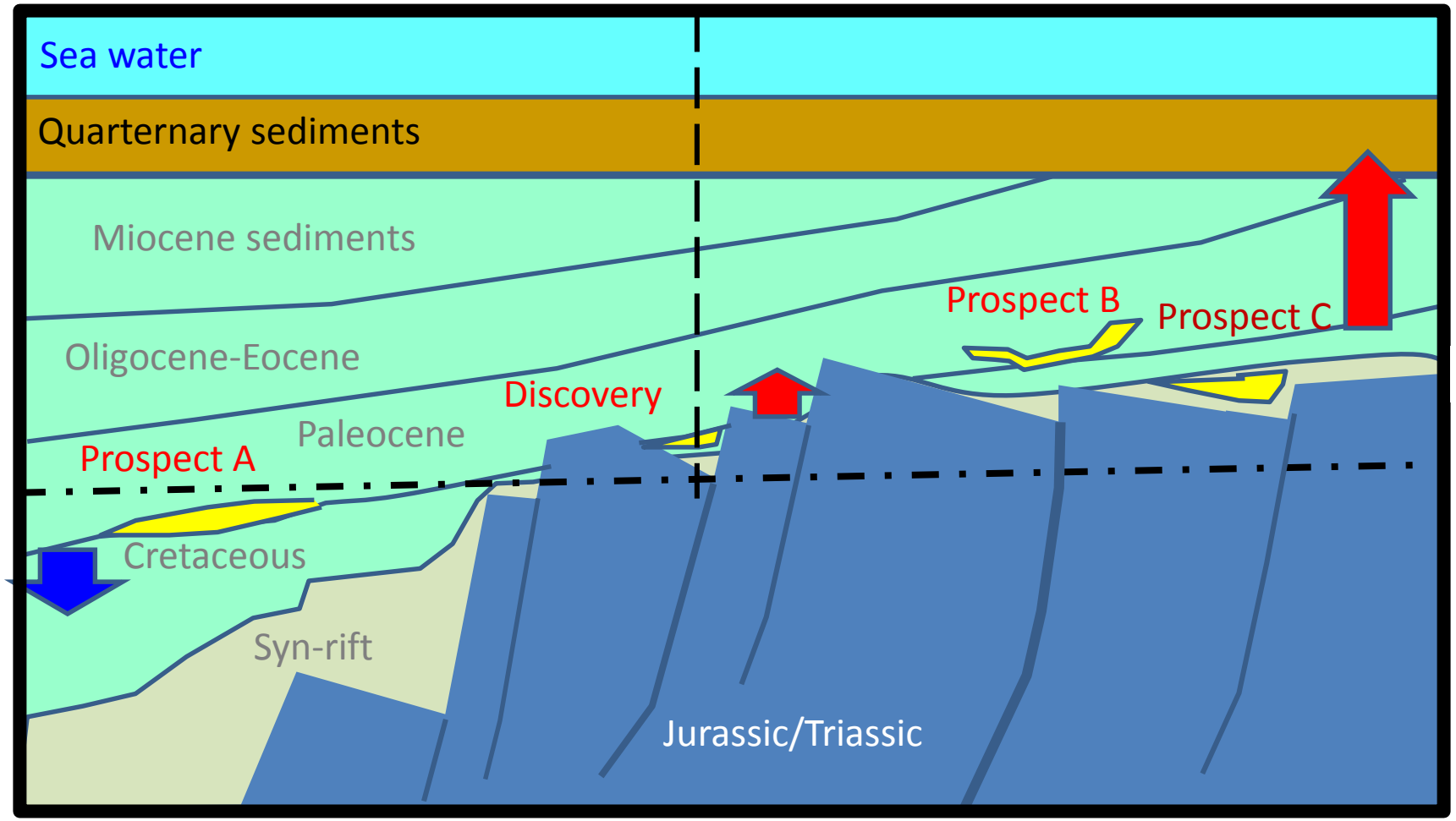
A «typical» present day geo-section offshore Norway



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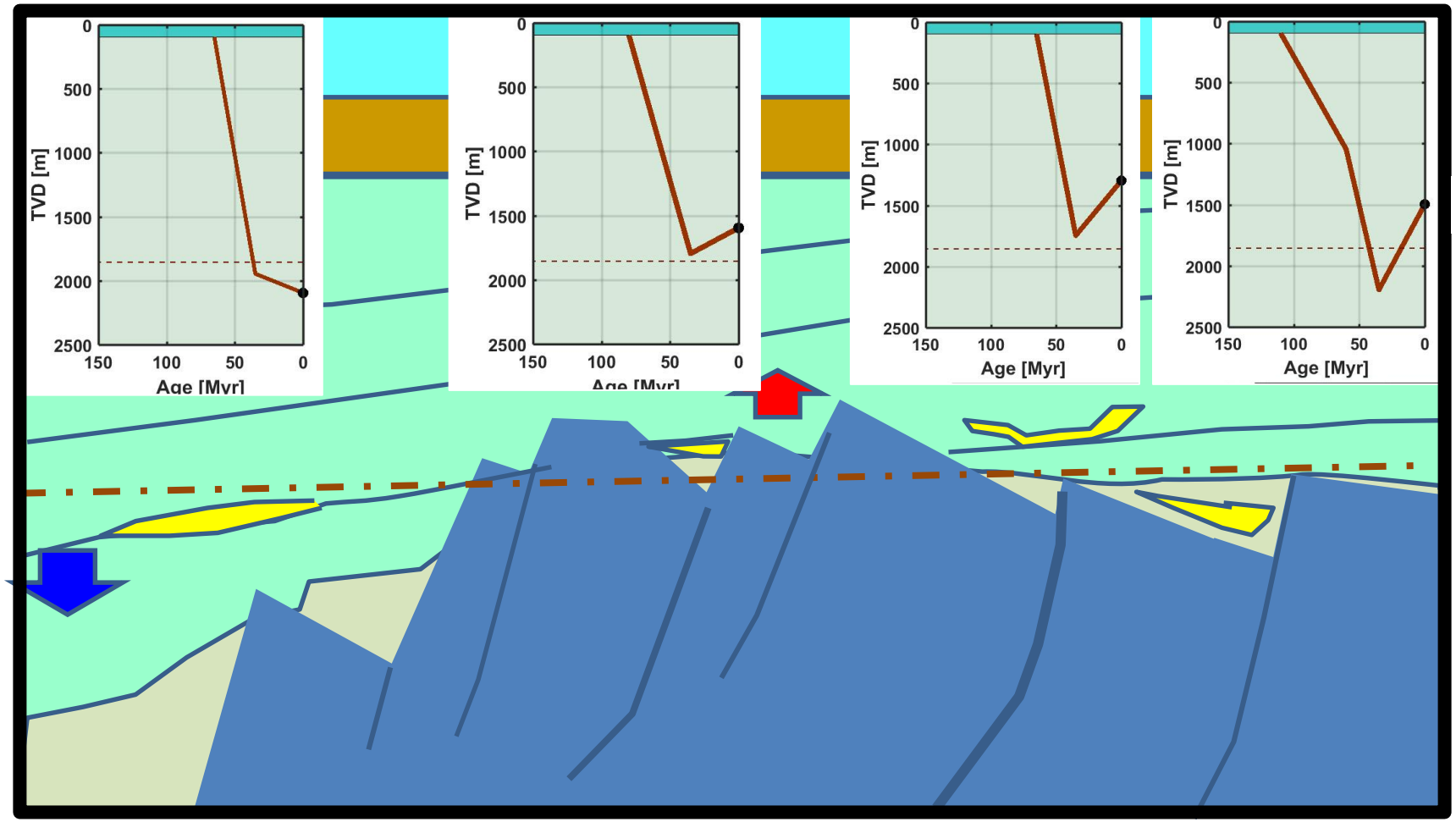
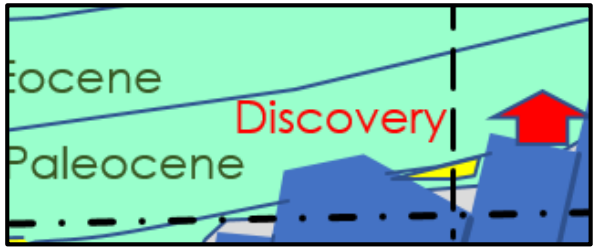
«Restoring» geo-section to maximum burial. Have prospects been into the frying pan?

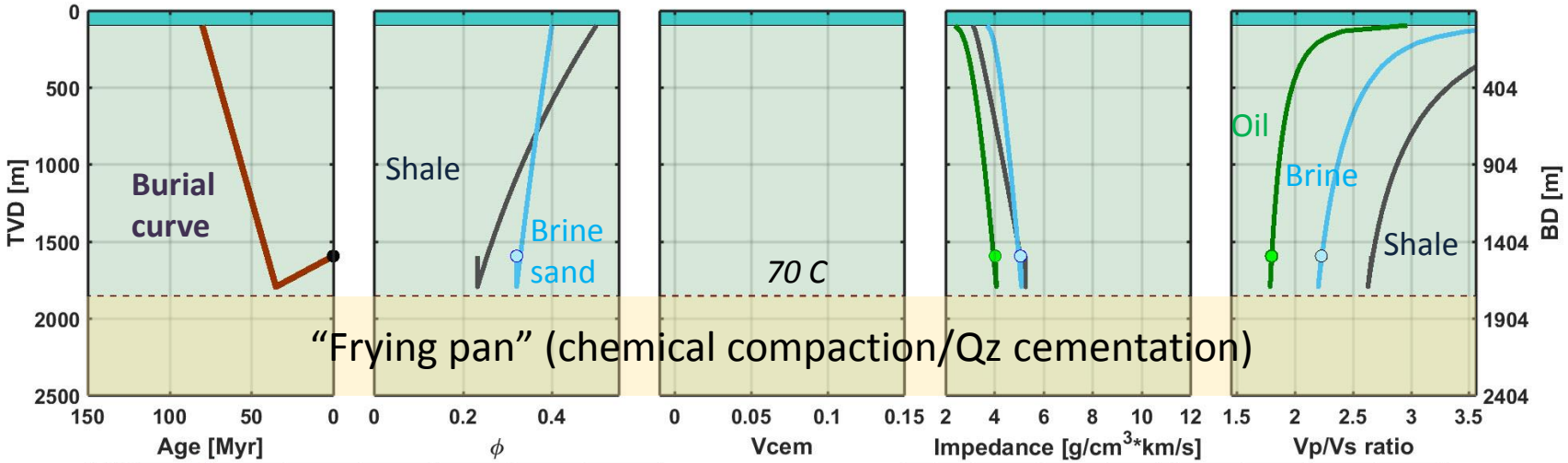


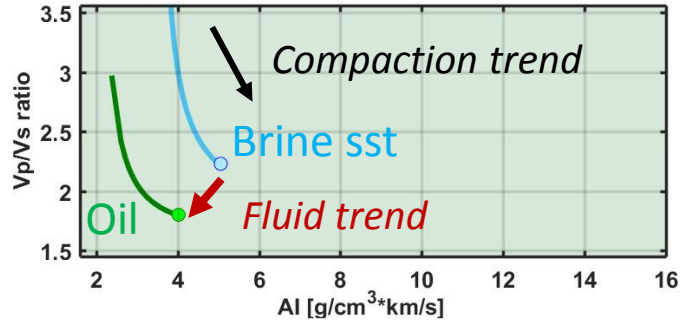
The "Frying Pan"
(T>70 C required for Qz-cem.)

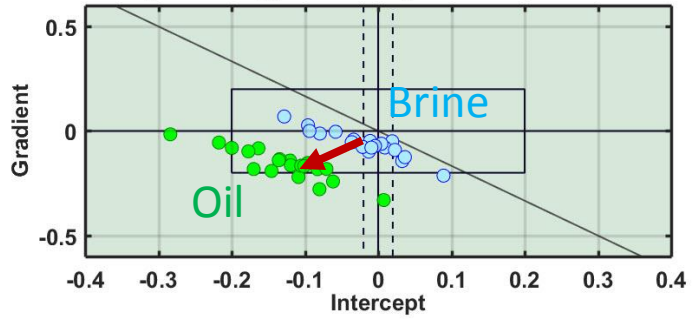
Burial constrained AVO modeling at “Discovery” well.

(Campanian sands w/oil give AVO class III)



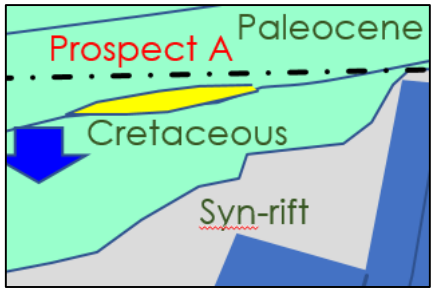


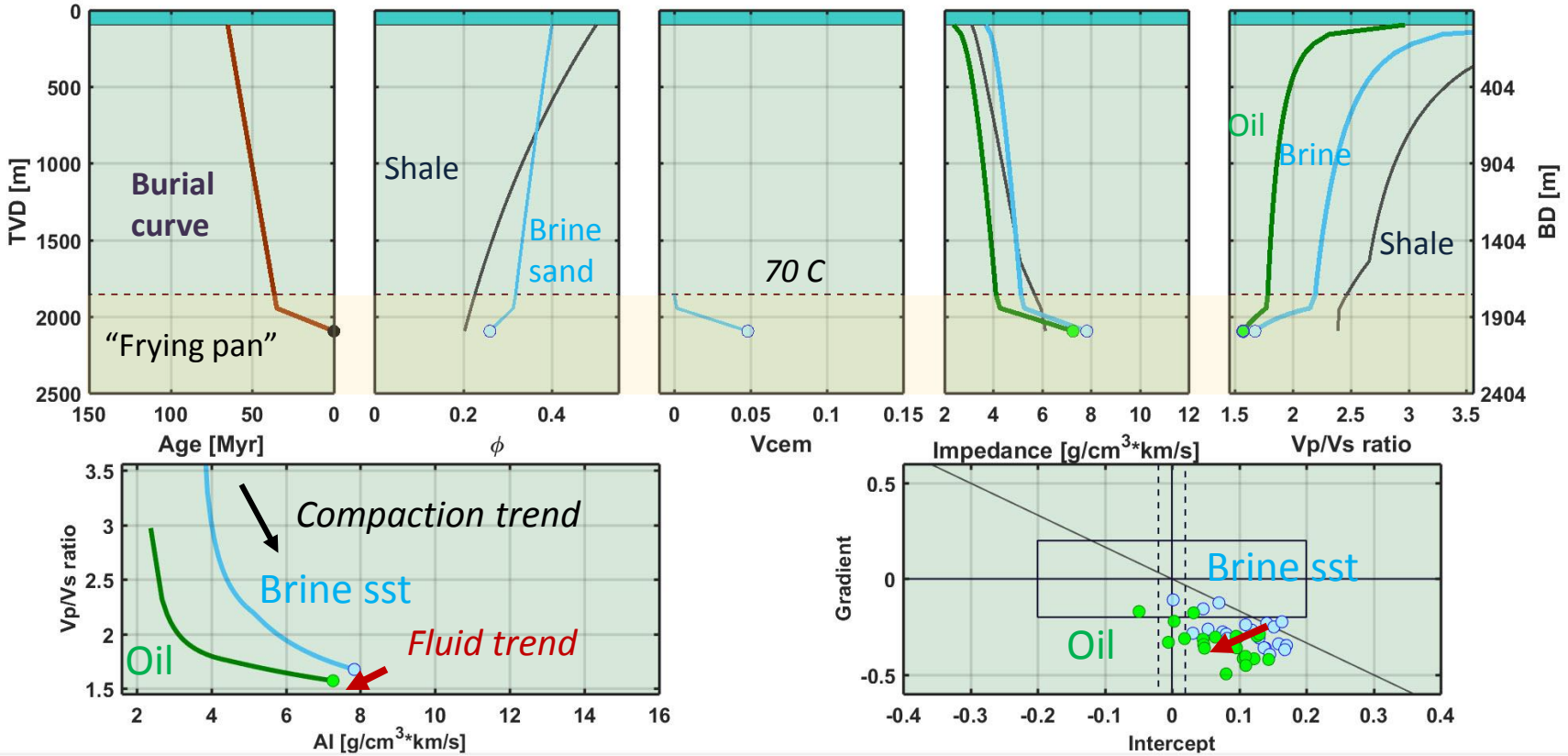




Burial constrained AVO modeling at prospect A (Paleocene sst)

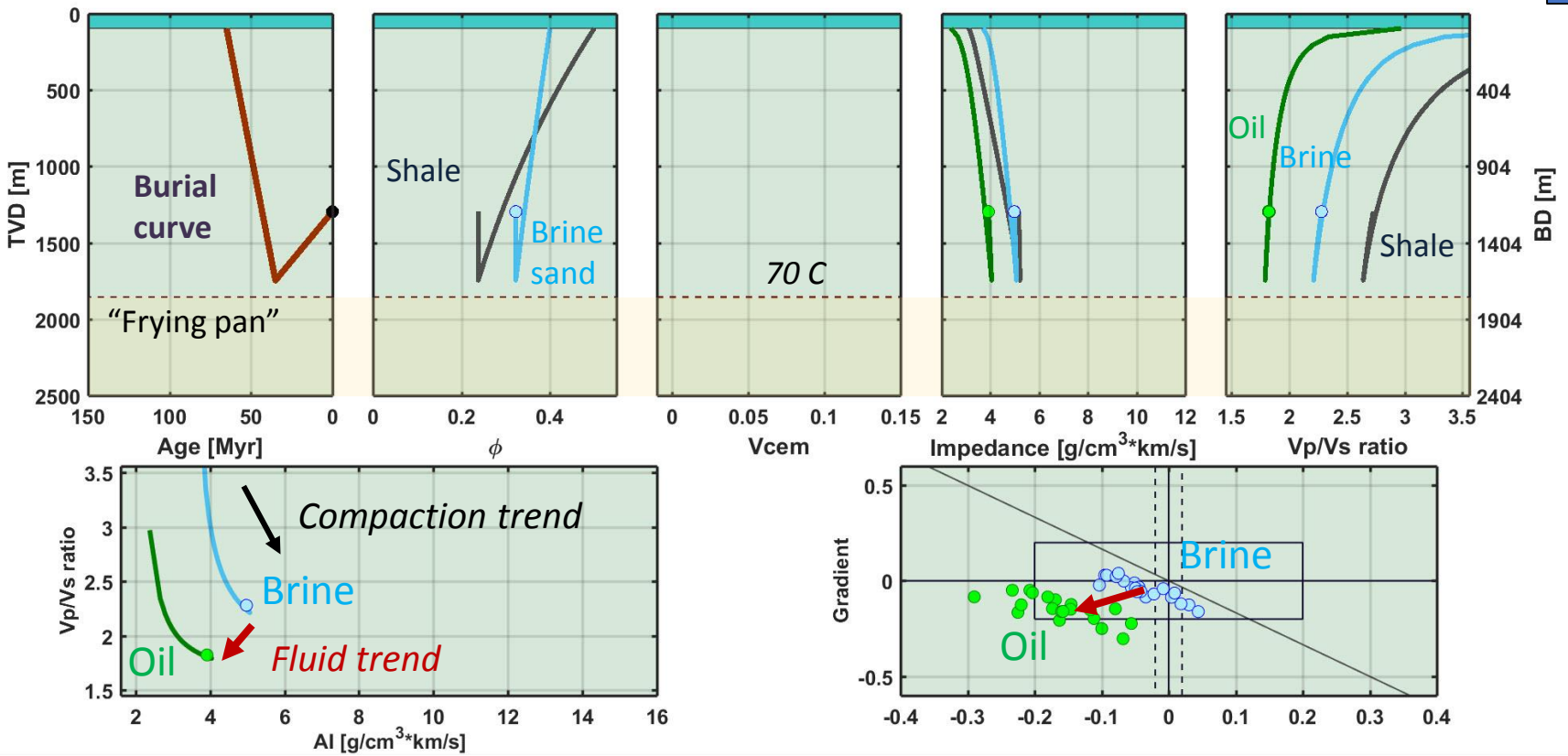
Oil-filled sst = AVO class I-IIp





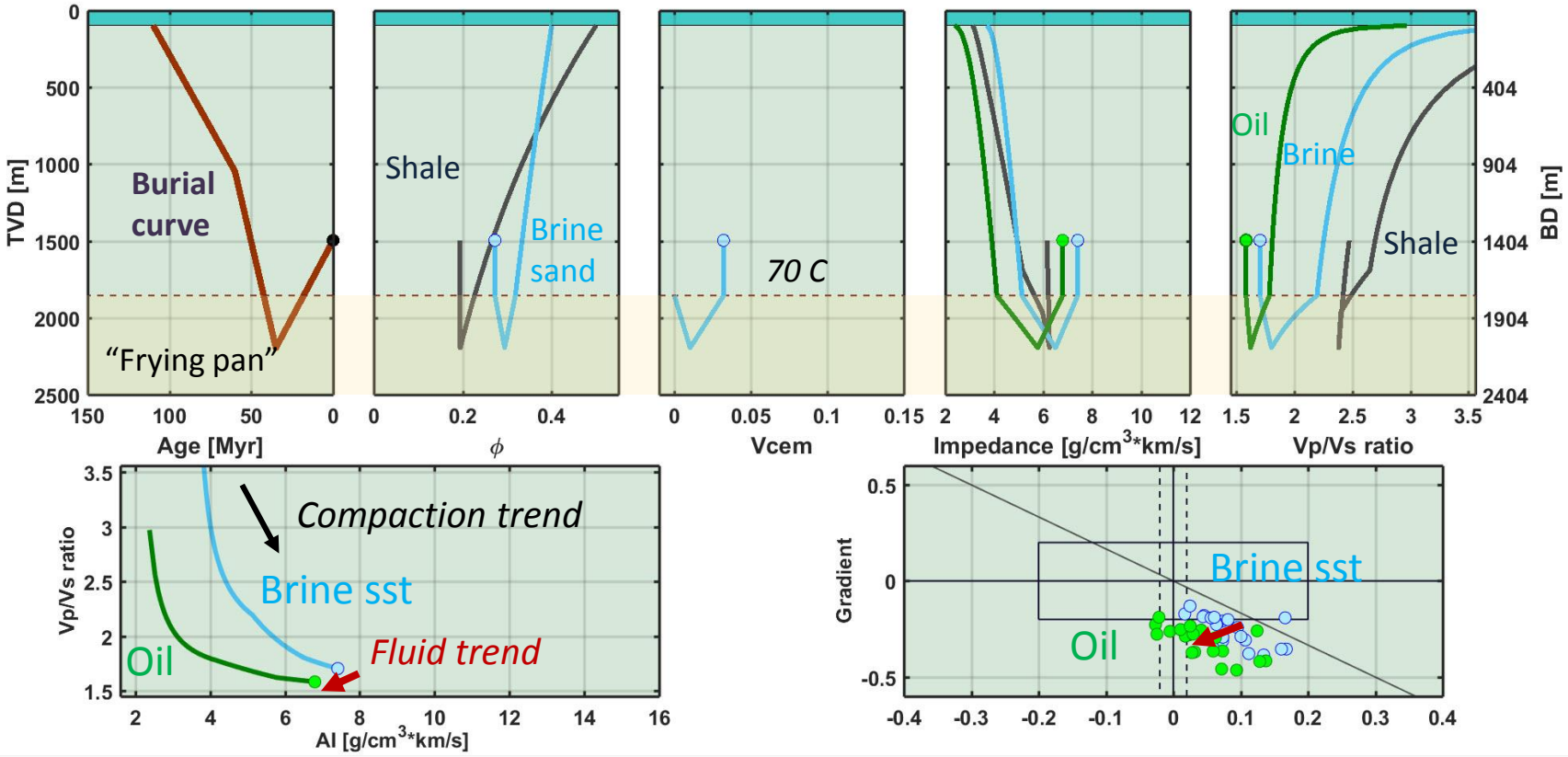
Burial constrained AVO modeling at prospect B (Paleocene sand)

Oil-filled sst = AVO class III



Burial constrained AVO modeling at prospect C (Aptian sst)

Oil-filled sst = AVO class IIp



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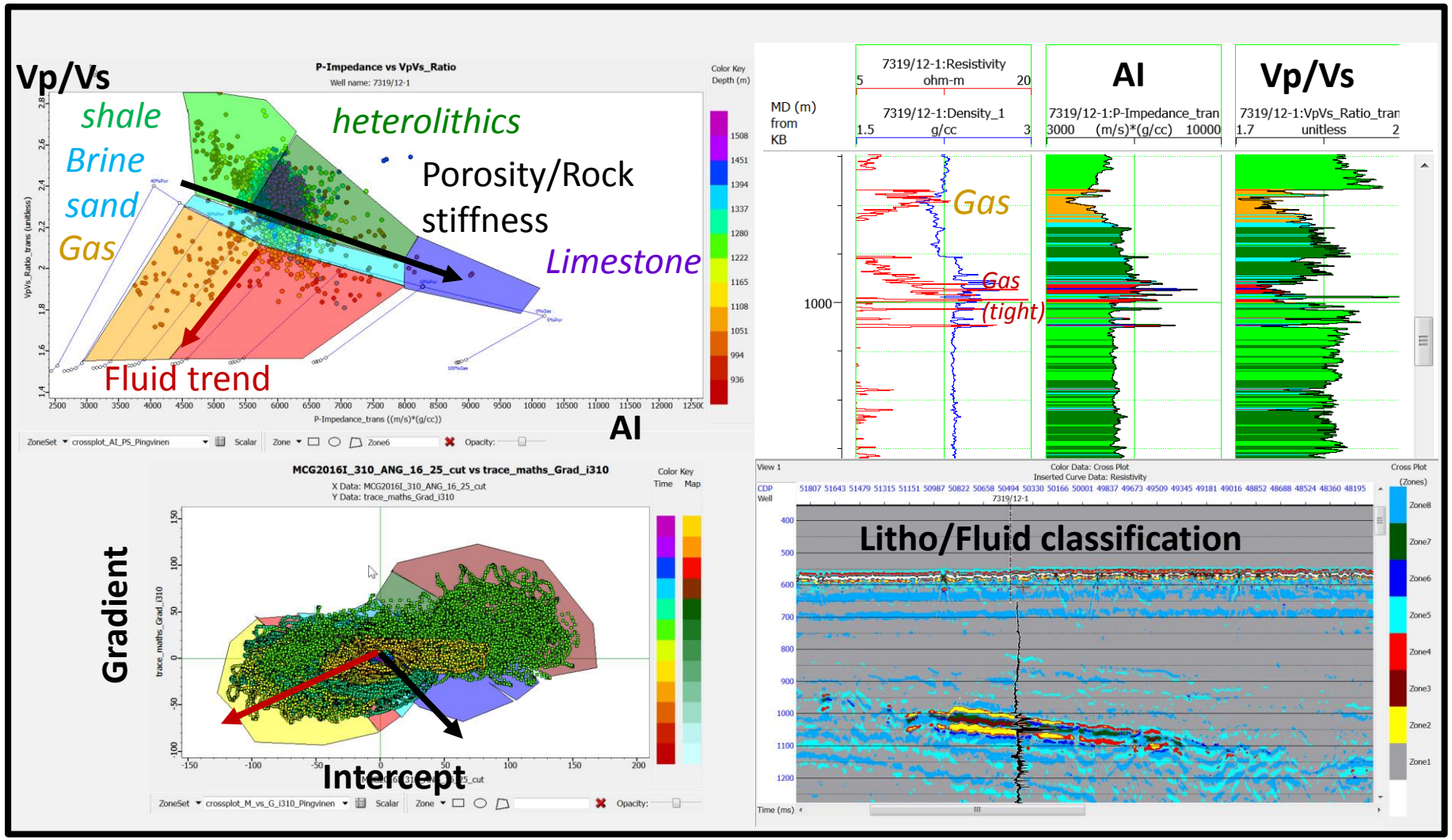
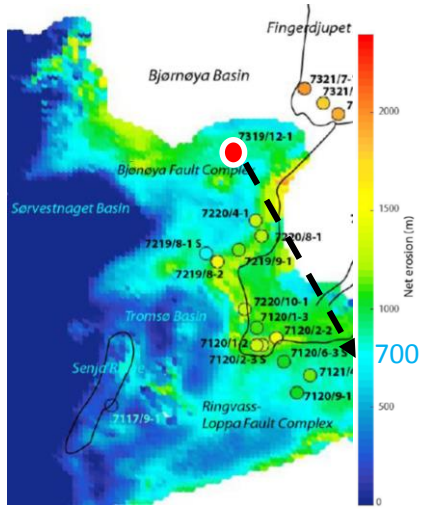
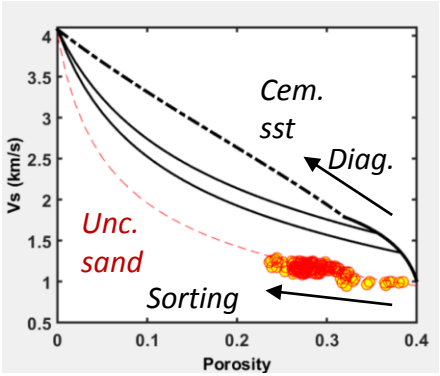
RPT and AVO analysis @Pingvin well 7319/12-1

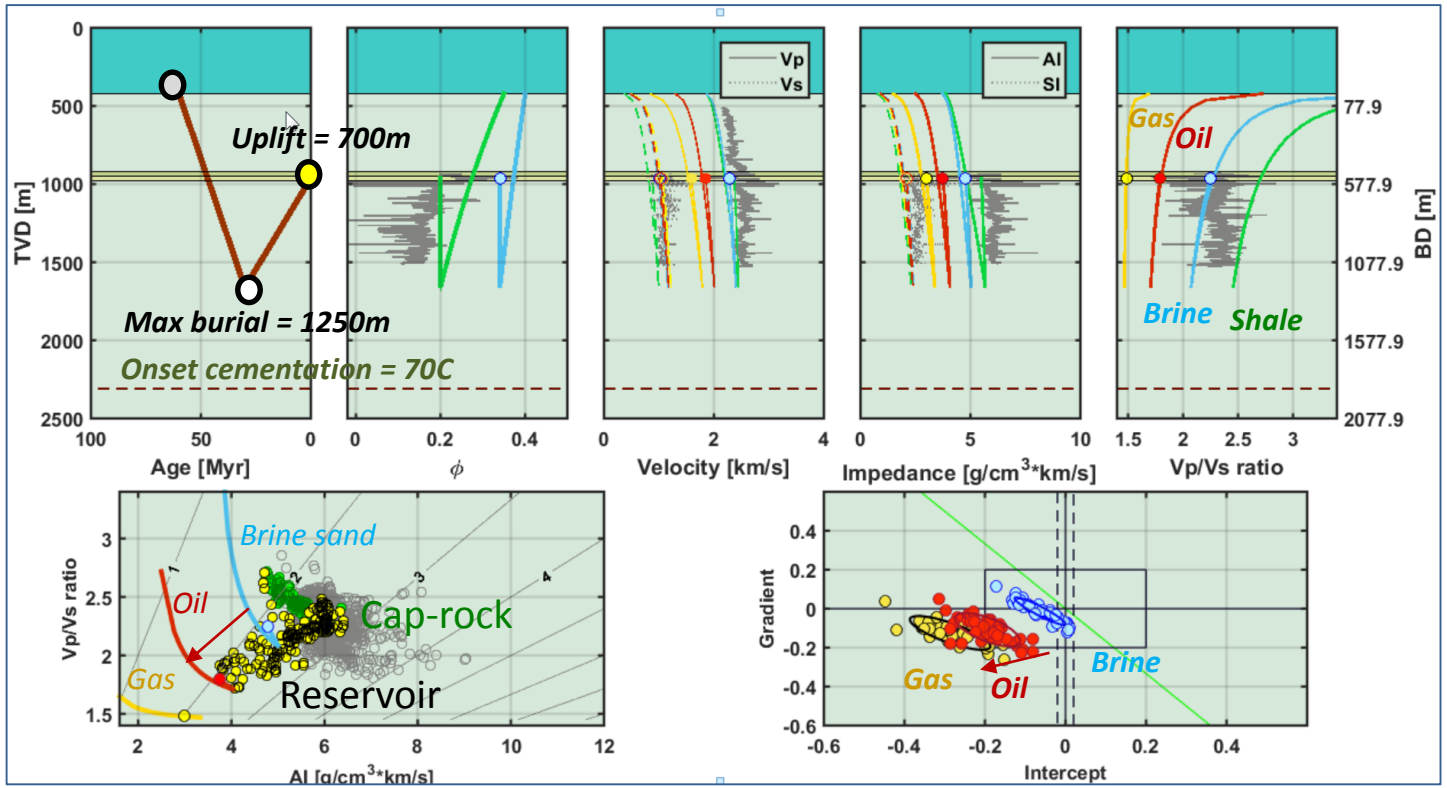


Burial analysis and simulated AVO signatures in Pingvin (7319/12-1)



Net erosion map from N. Johansen (2017)





The reservoir sands in Pingvin has not been buried deep enough to be cemented! Hence, great fluid sensitivity! AVO class III expected for any HC-fill.

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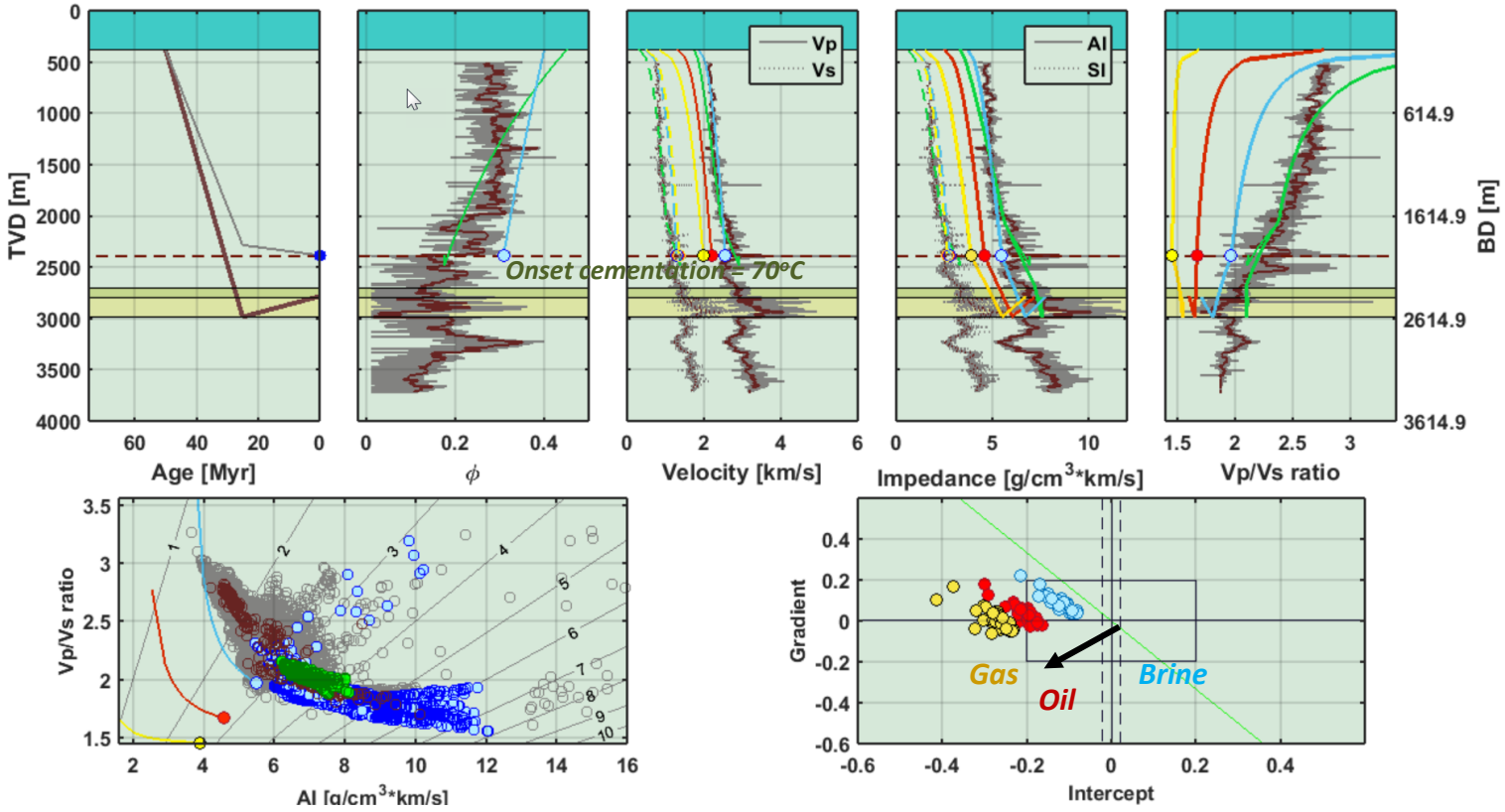
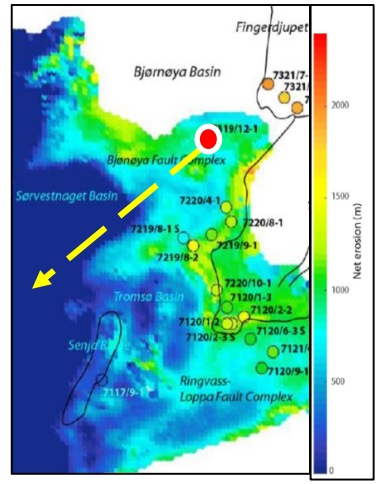
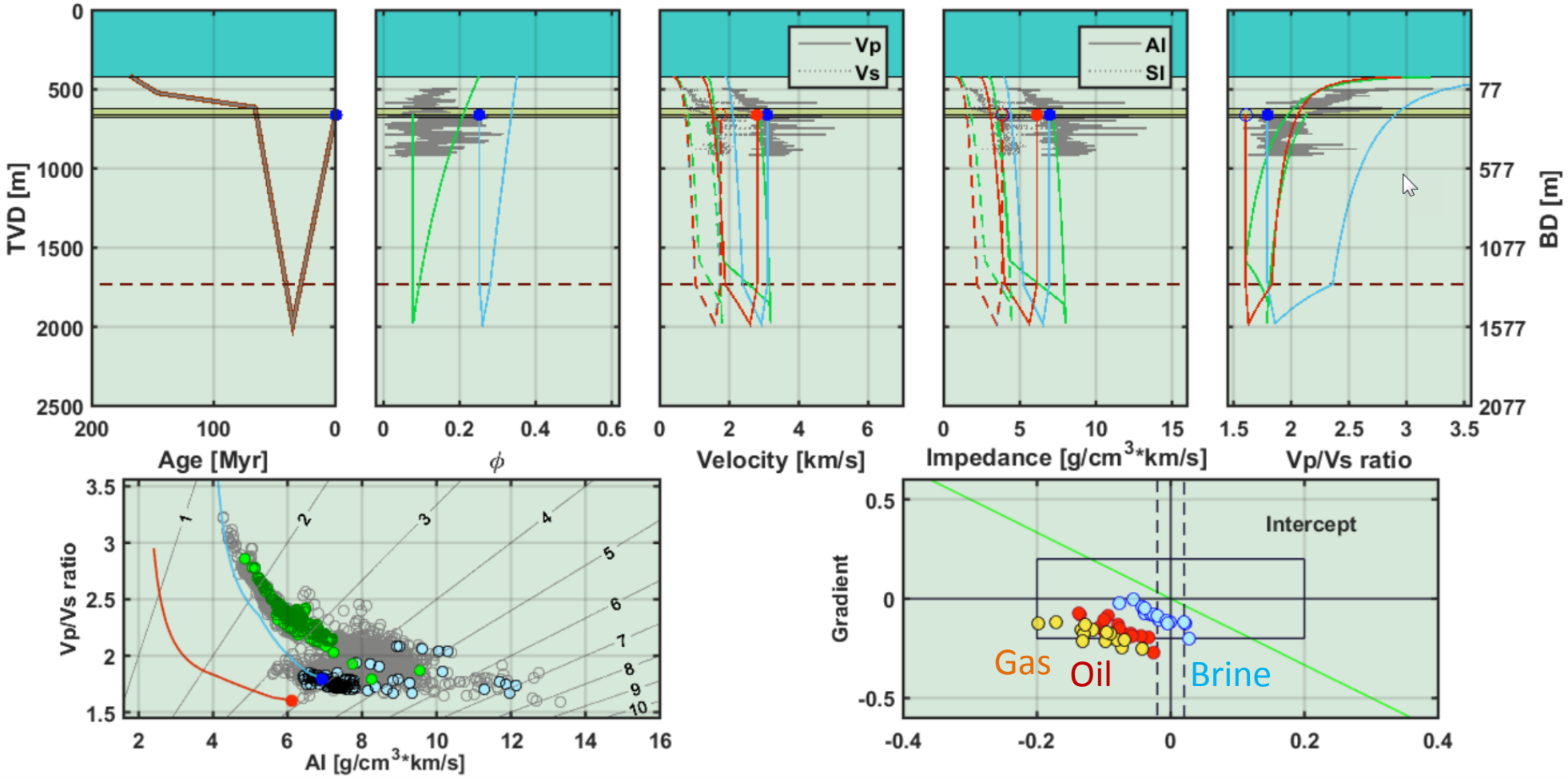
Eocene more deeply buried in Sørvestnaget Basin: Burial constrained AVO at well 7216/11-1S

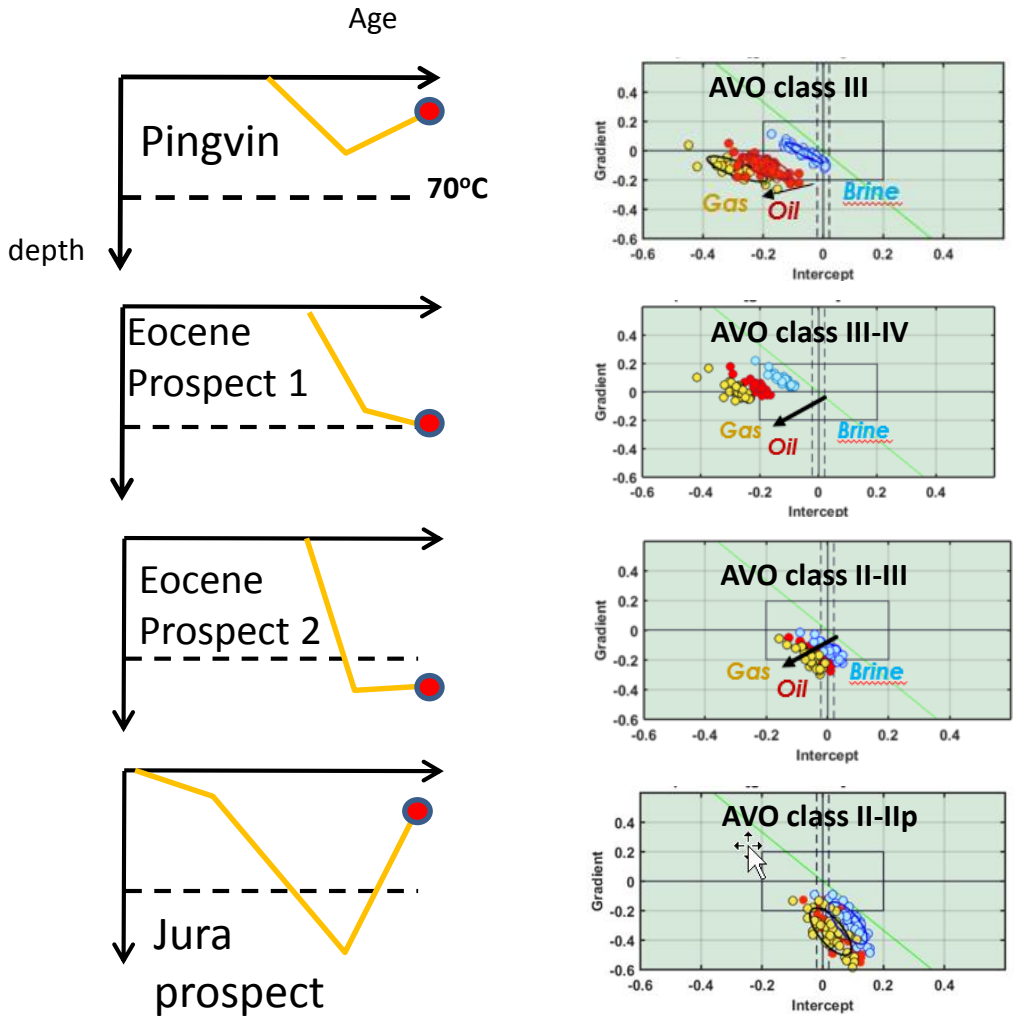


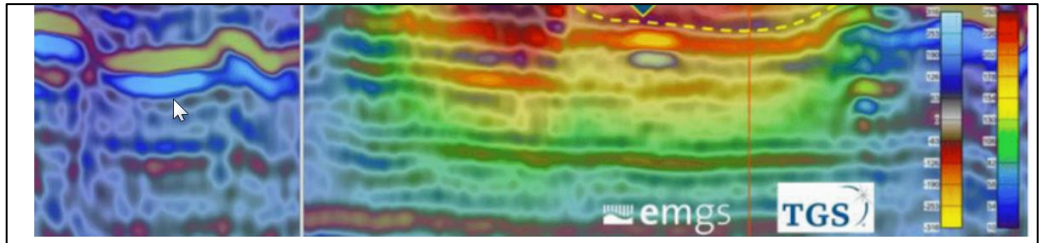


Wisting example
Net uplift=1500m (Temp grad=42.5C/km)



Summary:
How burial controls AVO and fluid sensitivity





For explorationists, prominent EM-anomalies have less value than sharp reflectors, according to Bent Kjølhamars team (c) EMGS/TGS

Fooled by seismic

Triassic prospects in the Hoop area are overlooked because they lack clear bright seismic reflectors.
Click To Tweet

04.10.2017 Halfdan Carstens Olje og gass

Conclusions

- The present day seismic signatures will reflect depositional and burial history, and this knowledge should be included in AVO and QI studies.
- **Rock physics modeling** can be **combined with burial modeling** for uplift estimation, to constrain low-frequency trends, and to model expected AVO signatures.
- Normally, bright seismic amplitudes and class II-III AVO signatures are only associated with unconsolidated to poorly consolidated sandstones.
- There is likely a lot of «hidden» hydrocabrons (esp. oil) in consolidated sandstone reservoirs with stiff rock frame and reduced fluid sensitivity, that can be challenging to discover during AVO and QI studies.

Acknowledgements

- Thanks to Ivan Lehocki at Lehocki Geospace for contributions to burial modeling codes.

- Thanks to MCG for AVO data on Pingvin

- Thanks to FORCE for the invitation