應用地質研究所
Graduate Institute of Applied Geology

Shale transformations and physical properties—Implications for seismic expression of mobile shales

Soto, J. I., Hudec, M. R., Mondol, N. H., & Heidari, M. (2021). Shale transformations and physical properties—Implications for seismic expression of mobile shales. *Earth-Science Reviews*, *220*, 103746

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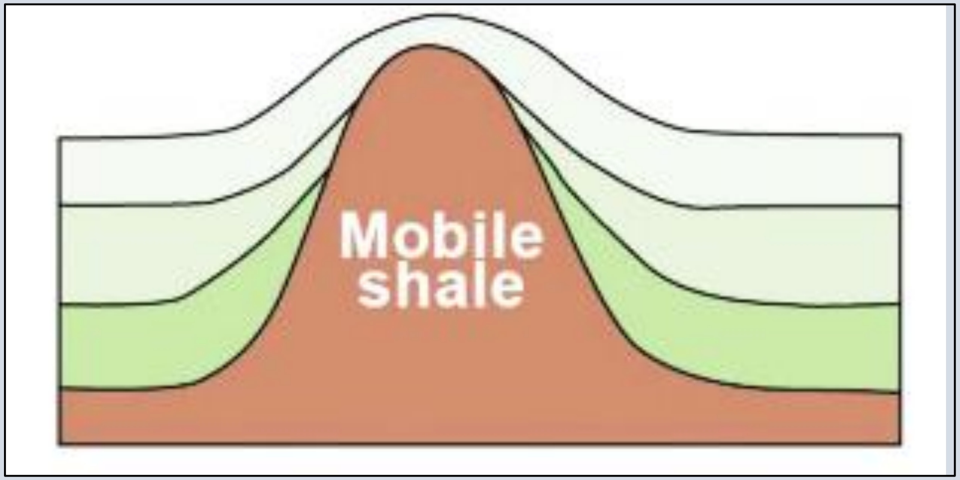
Date: 2022-05-13

Content

Motivation and Goal

- Fluid overpressure in Shale?
- Physical properties and transformations in Shale?
- Seismic expression of Mobile Shale?



- The goal is to understand sources of fluids and shale transformations during burial and how it affects seismic imaging of mobile shales

Introduction

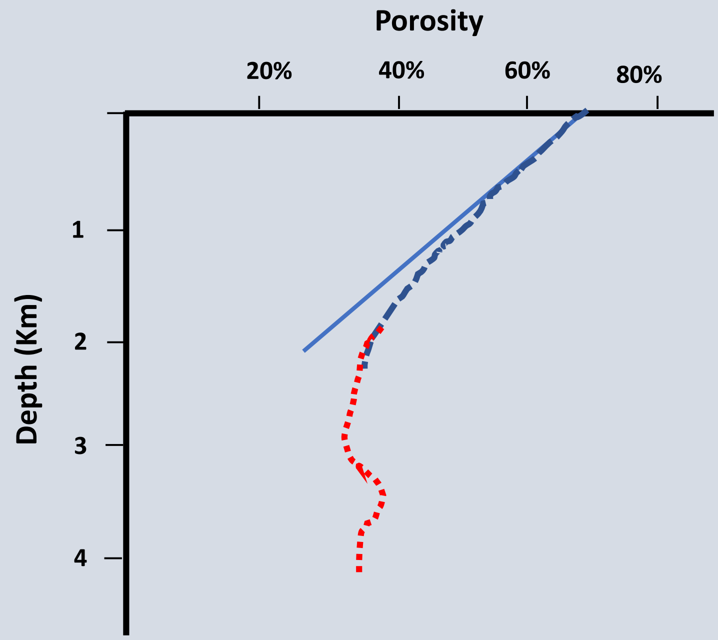
Shales

- **Claystone**: >66% of clay grains have a diameter ≤4 µm
- **Mudstone**: 33-66% silt particles having diameter of 4-62.5 µm

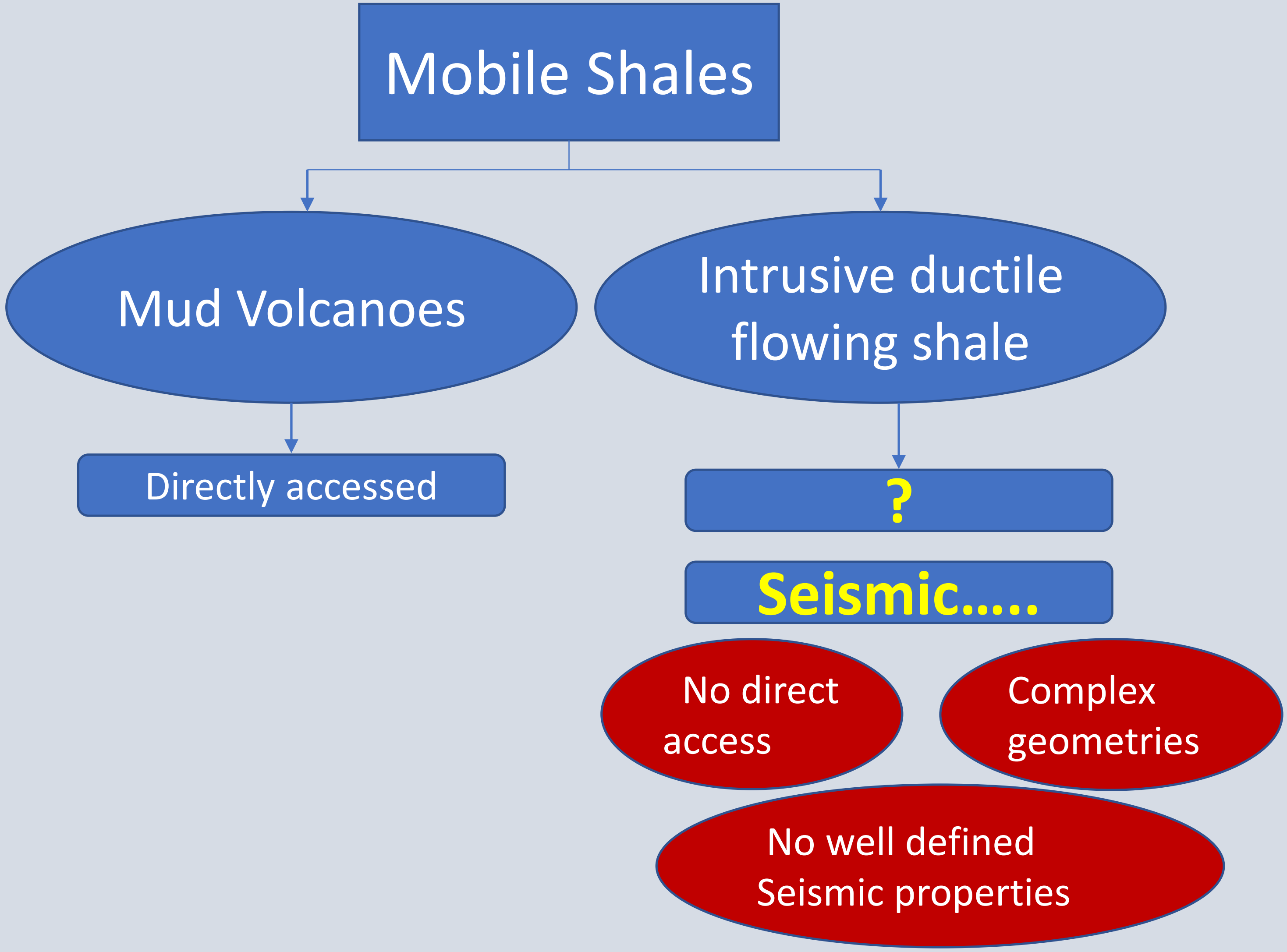
Fluid overpressure in Shale?

- Muds and clays deposit having water as their constituent and later due to compaction, the water cannot escape restoring hydrostatic pressure

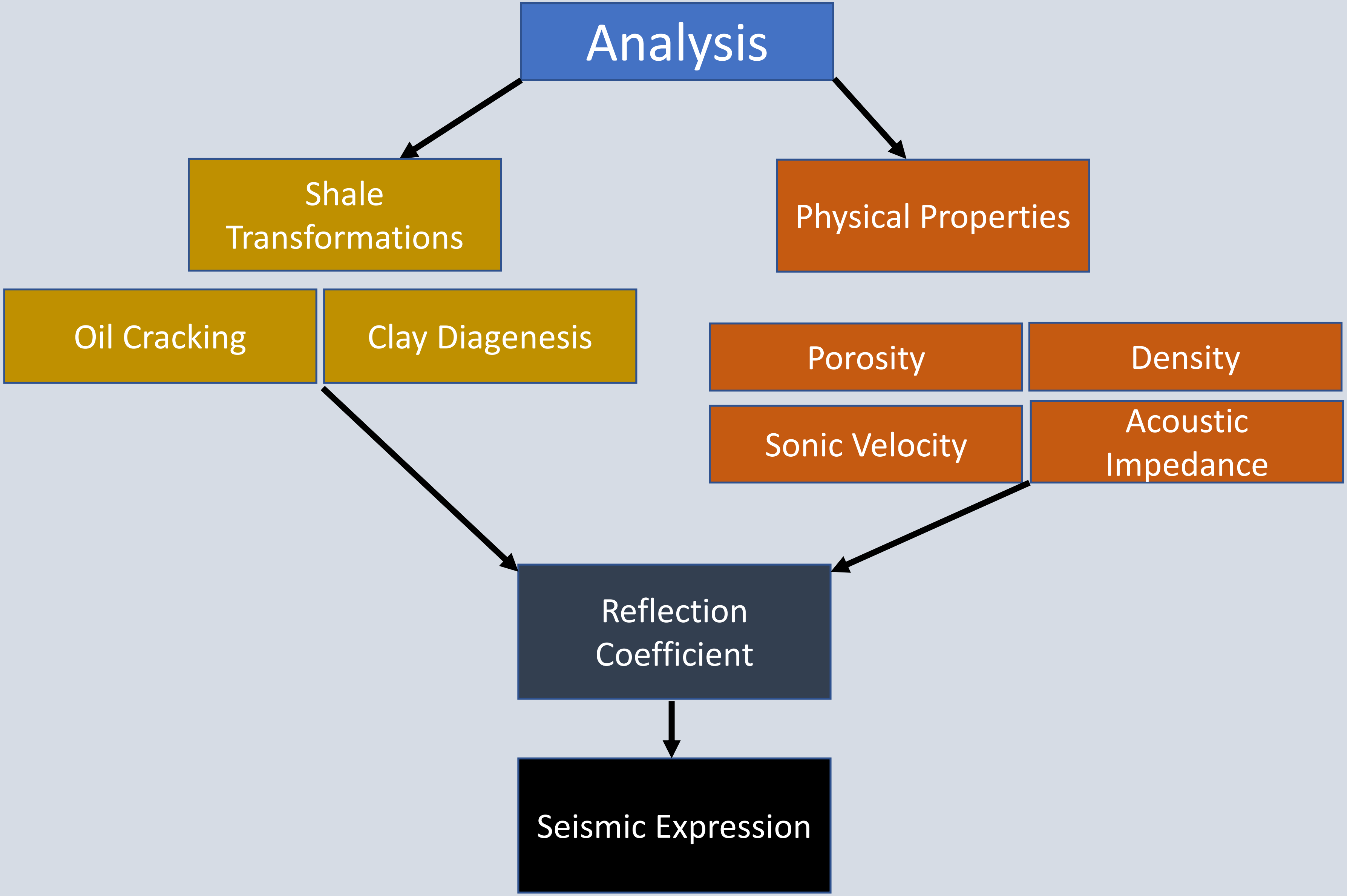
- Low permeability retards fluid escape both vertically and horizontally



Introduction



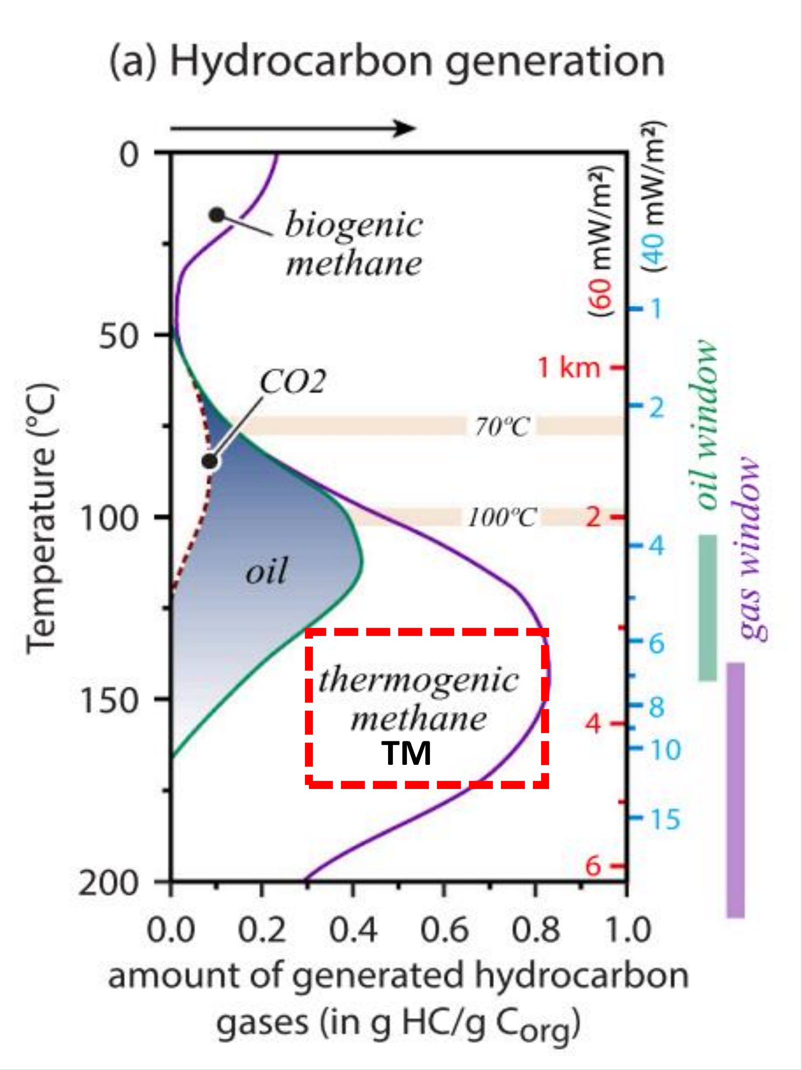
Workflow


Analysis
Shale Transformations
Physical Properties
Oil Cracking
Clay Diagenesis
Porosity
Density
Sonic Velocity
Acoustic Impedance
Reflection Coefficient
Seismic Expression

Shale Transformations

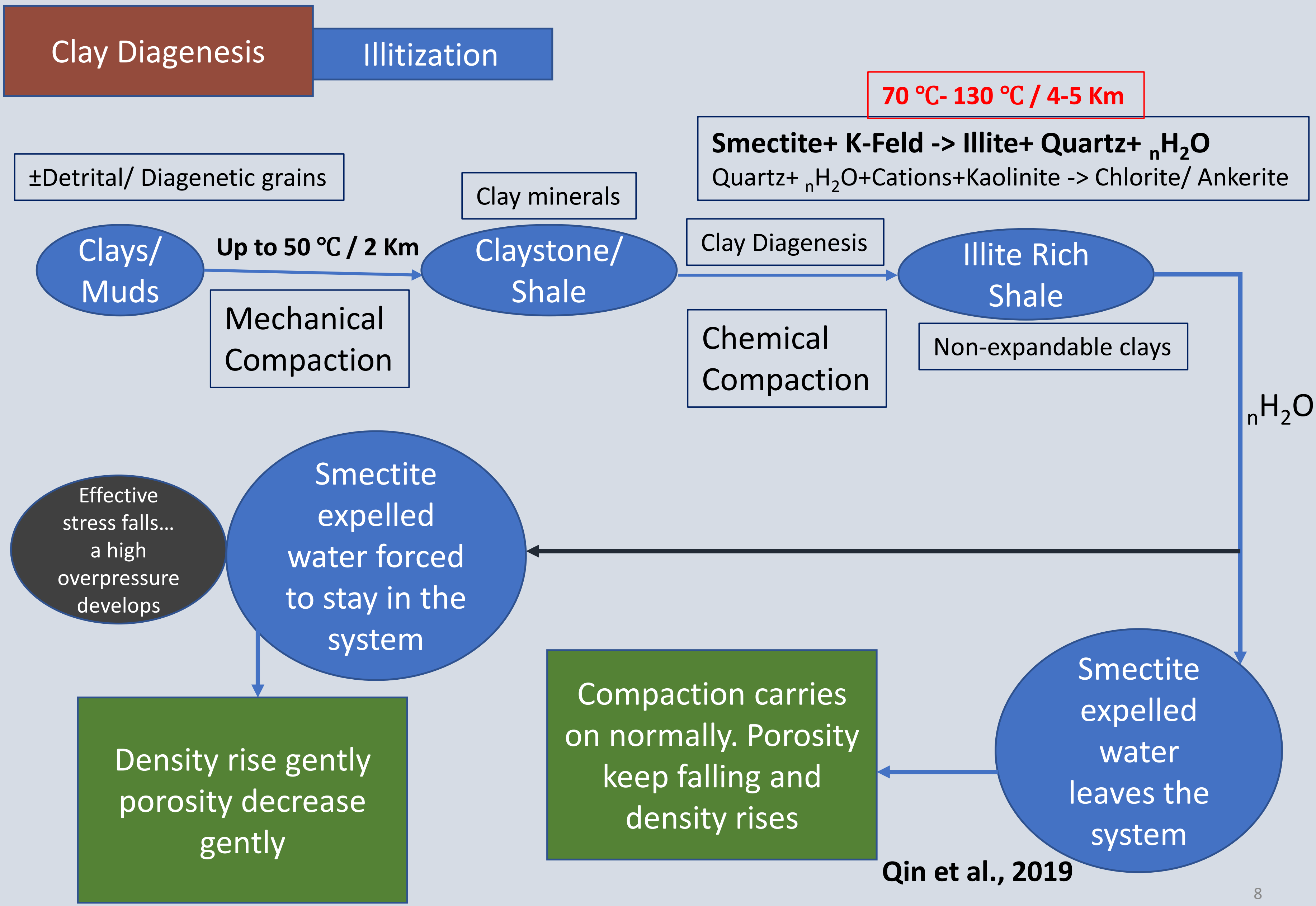
Oil Cracking

- Oil changes to methane at depths around 3-5 km
- **140-200 MPa pressure rise (TM)**



Hansom and Lee, 2005

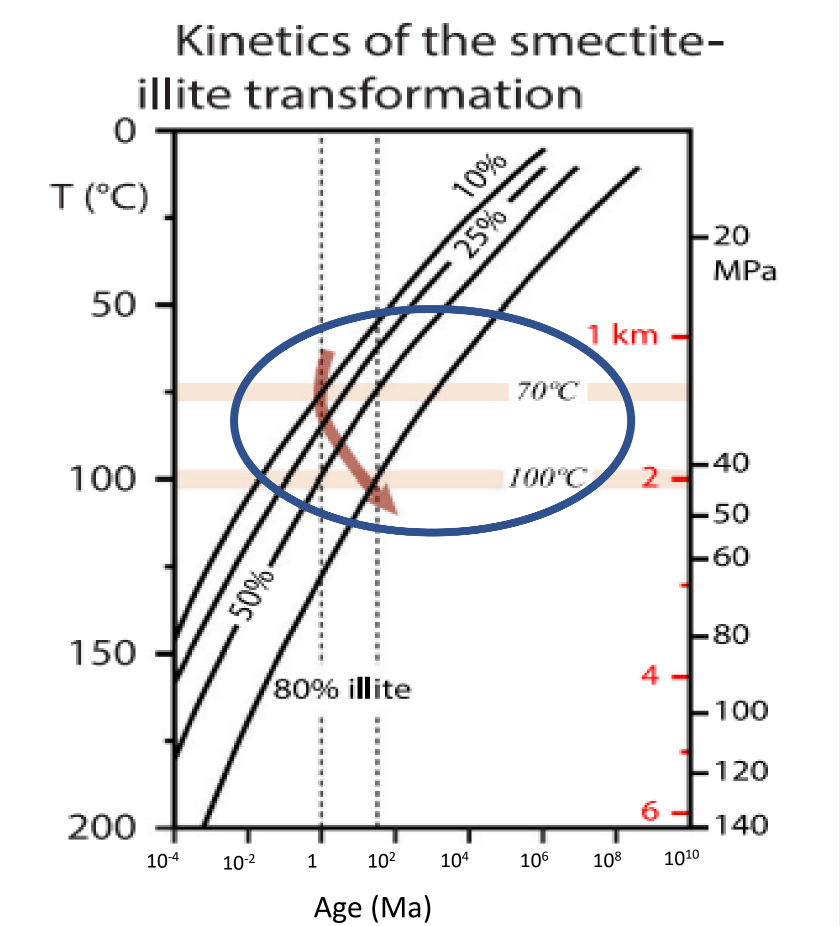
Shale Transformations



Shale Transformations

Clay Diagenesis

- **Temperature and time relationship for smectite to illite transformation**

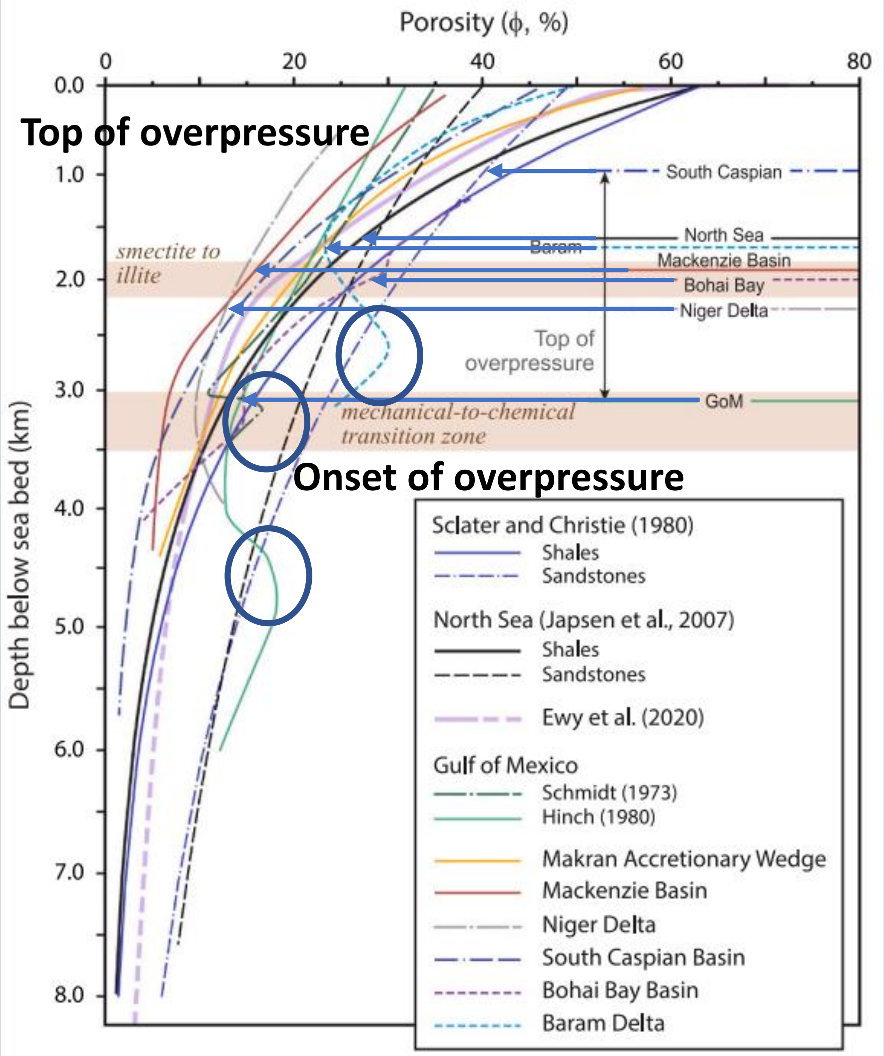


Modified from Soto et al., 2021

Physical Properties

Porosity

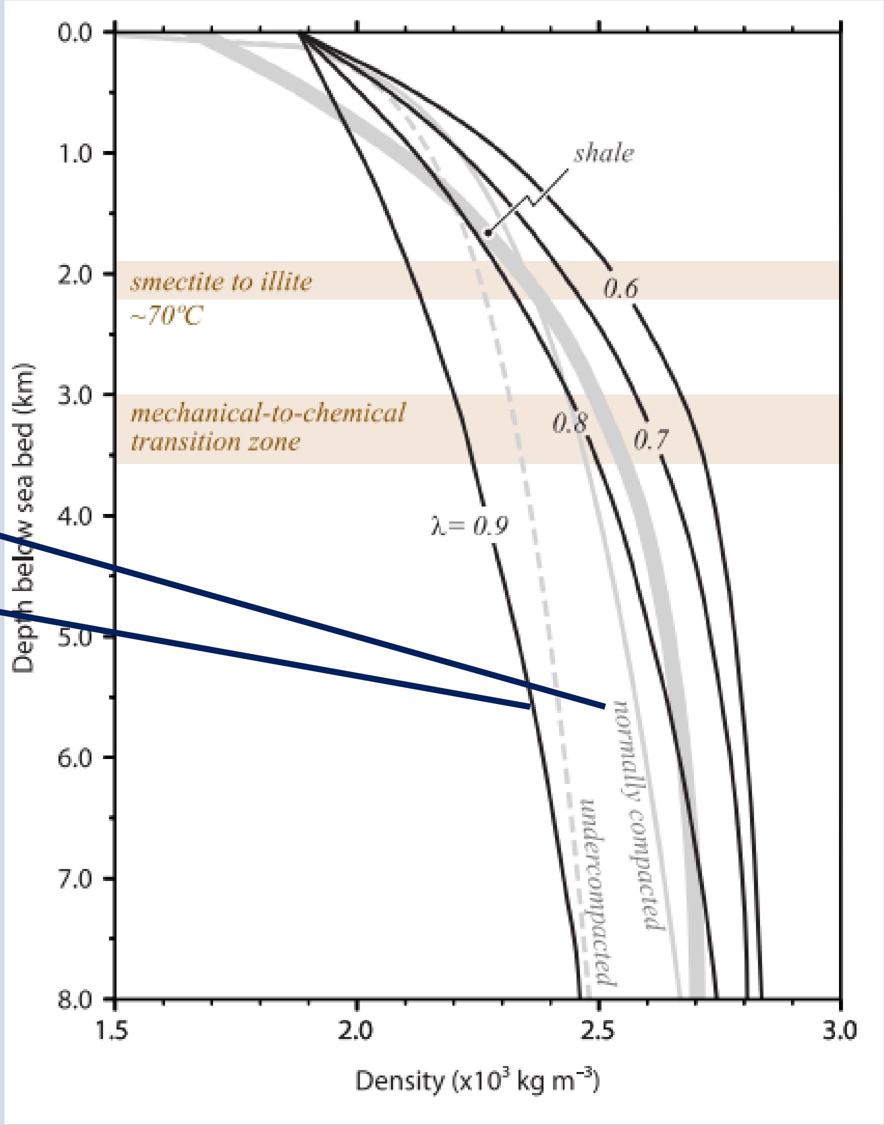
- **Top of overpressure**: Porosity gently decrease (**Smectite-Illite**)
- **Onset of overpressure**: A steep increase of porosity (**Thermogenic Methane**)
- Methane has more influence in rising the fluid overpressure in shale compared to water



Physical Properties

Density

- Gentle increase of density with depth is indicative of the onset of overpressure
- λ= pore-fluid pressure ratio=
- pore-fluid pressure/ lithostatic stress
- λ= 0.7-0.8 (**normally compacted**)
- λ= 0.8-0.9 (**undercompacted**)

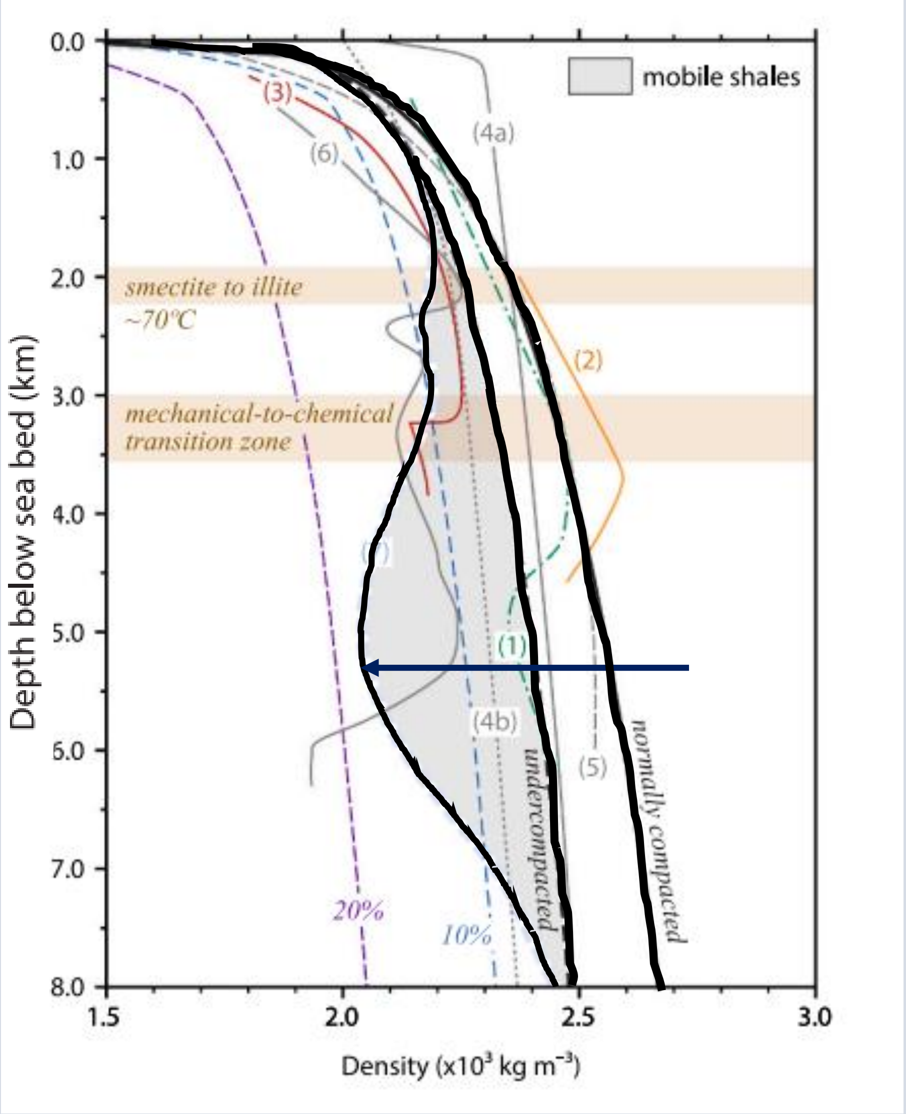


Physical Properties

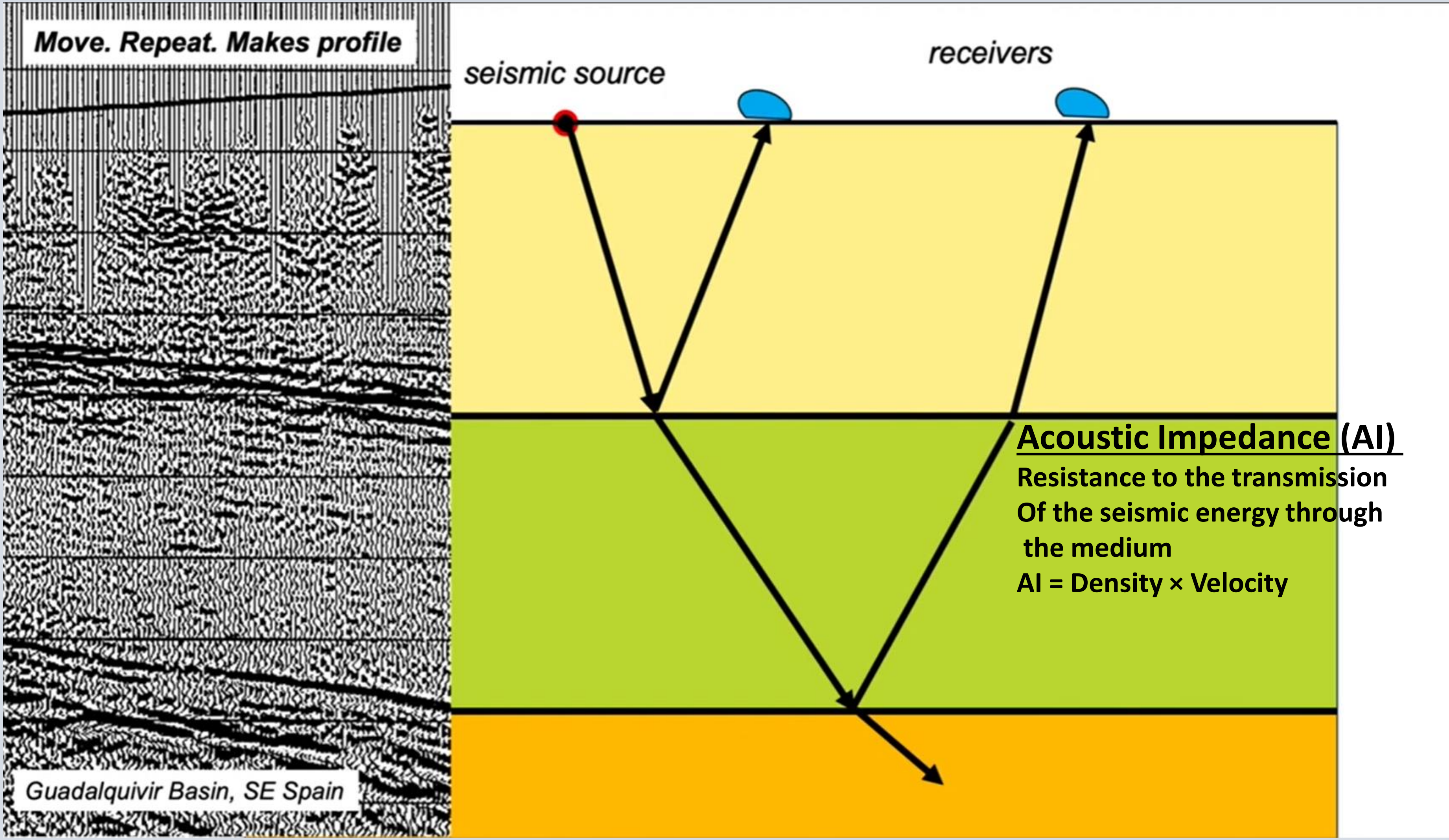
Effects of water and methane on the density of mobile shales

Density:

Normally compacted shale> undercompacted shale> Mobile Shale



Physical Properties



Acoustic Impedance (AI)

Resistance to the transmission Of the seismic energy through the medium

AI = Density × Velocity

Physical Properties

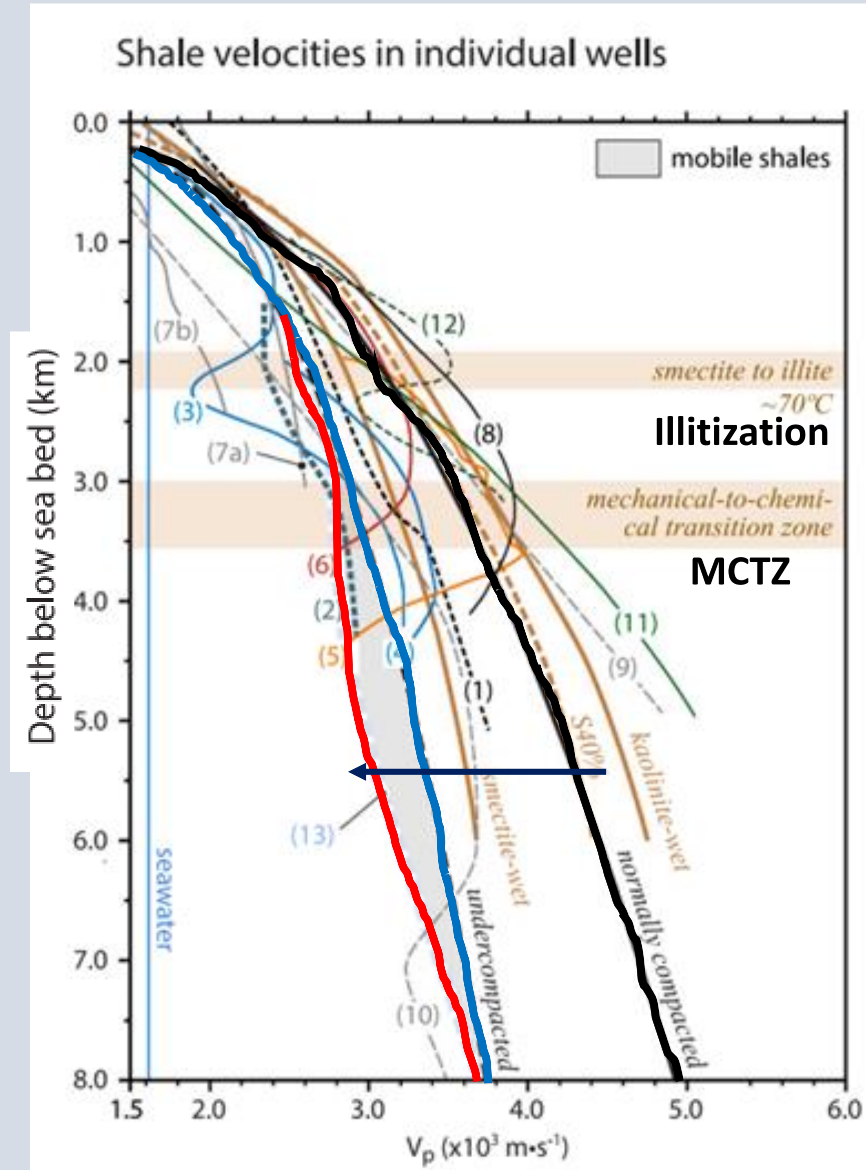
Sonic velocities of mobile shales

The velocity at which sound waves travel in a particular medium

- Density controls Sonic Velocity
- Most of data:

  At 2 Km: Illitization drops V_p

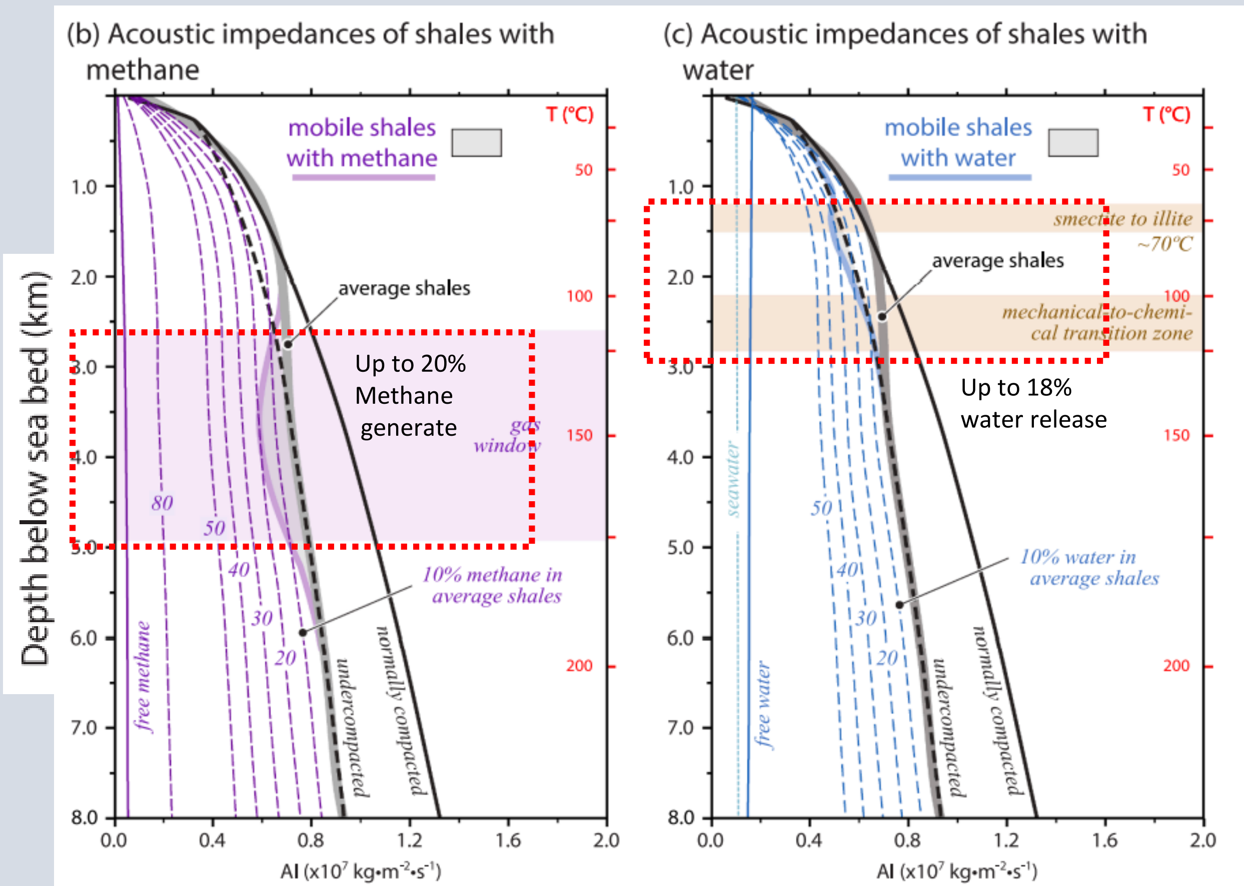
  At 3.5 Km: MCTZ drops V_p



Physical Properties

Acoustic Impedance (AI)

- AI= Density × Sonic Velocity
- Increase in sonic velocity increases AI

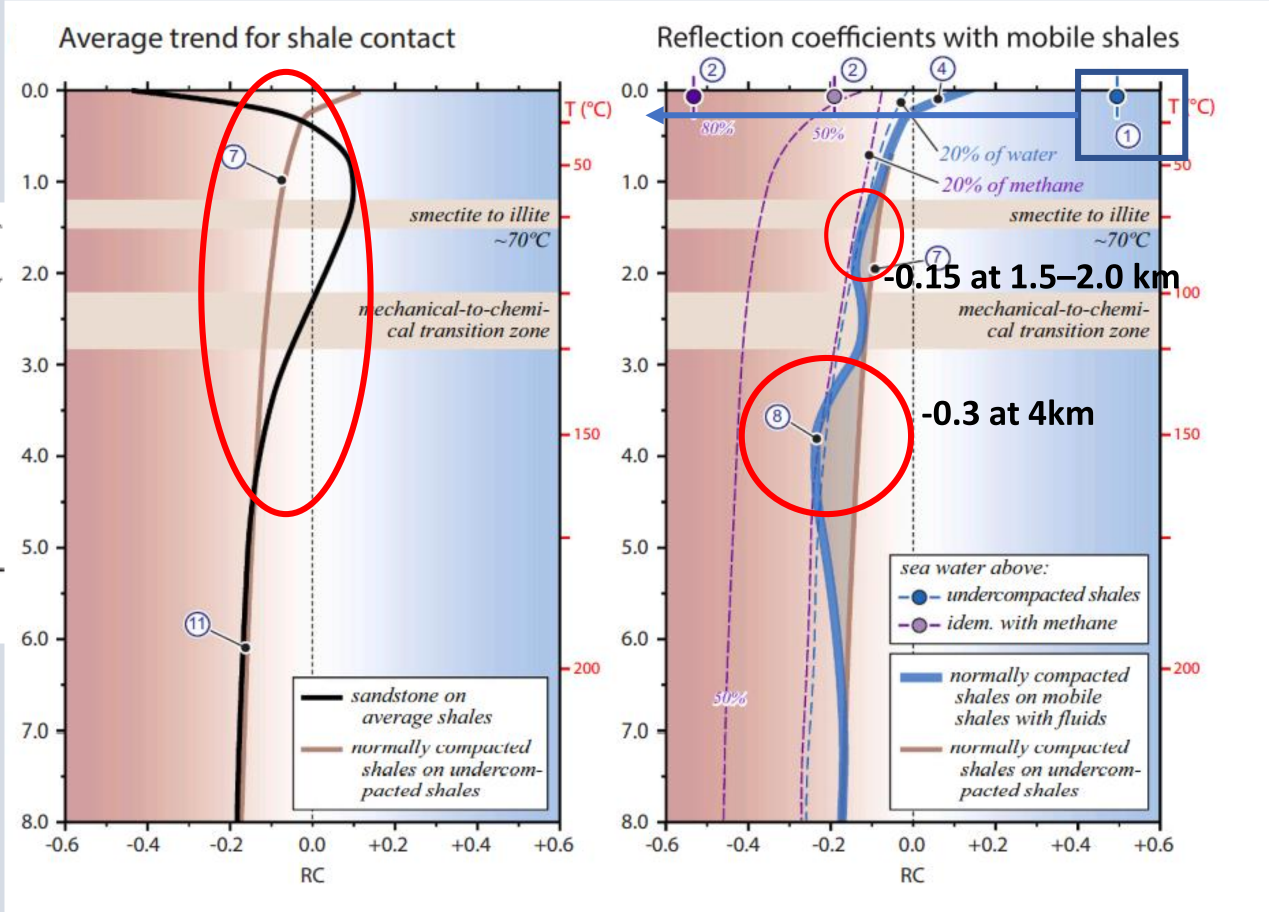


NIST, 2008

Physical Properties

Reflection Coefficient (RC)

- The proportion of seismic wave amplitude reflected wave (RV) from an interface to the incident wave (IV) amplitude. If 10% of the amplitude is returned, then the reflection coefficient is 0.10
- +ve RC : RV polarity same as IV, -ve RC: RV polarity opposite to IV



$$RC = \frac{AI_2 - AI_1}{AI_2 + AI_1}$$

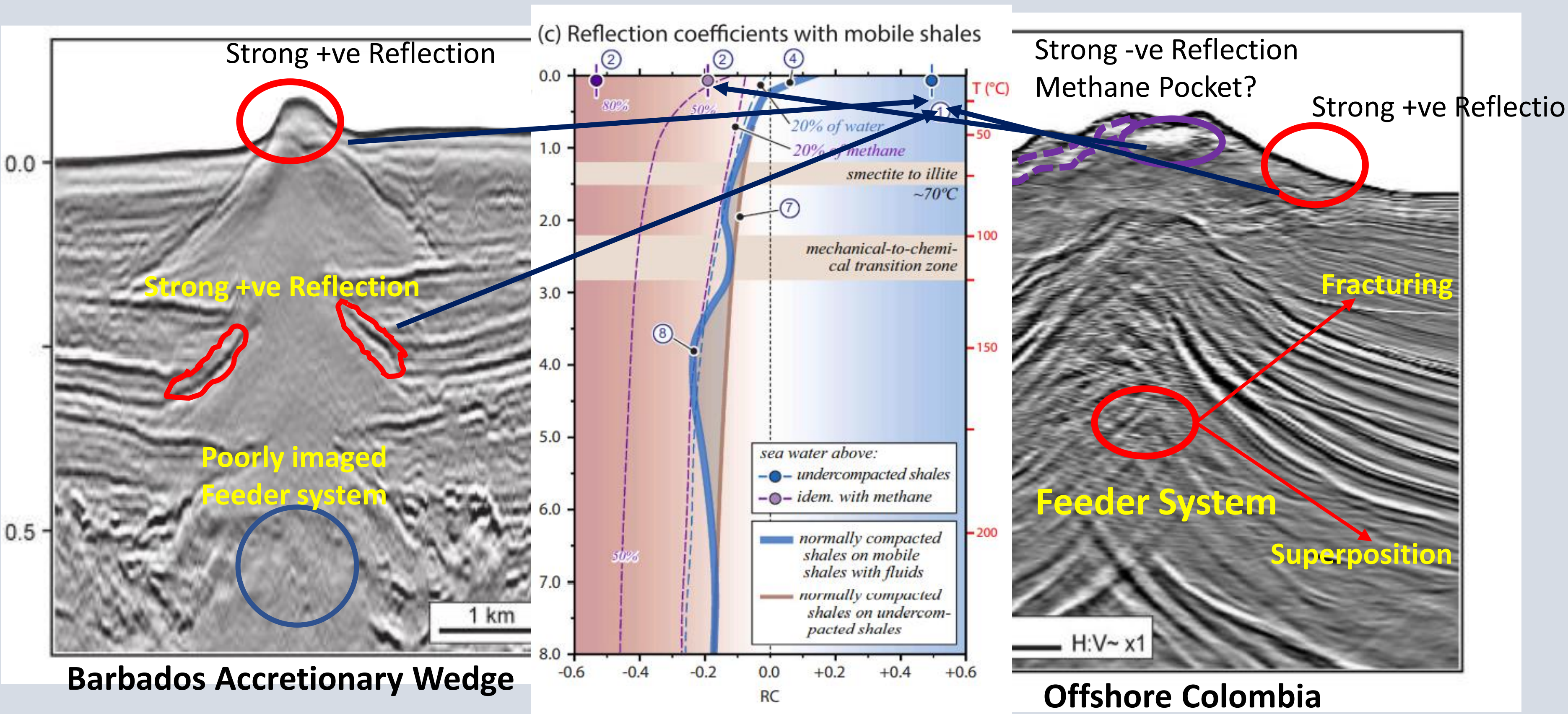
AI_1 = Impedance of upper layer

AI_2 = Impedance of lower layer

Seismic Expressions

Near-surface mud volcanoes

- Seabed: slight negative reflectivity
- Carbonate: very strong polarity (+ve) than other rock types
- Fluids (Methane and water) will make the reflectivity of shale, very weak (-ve)

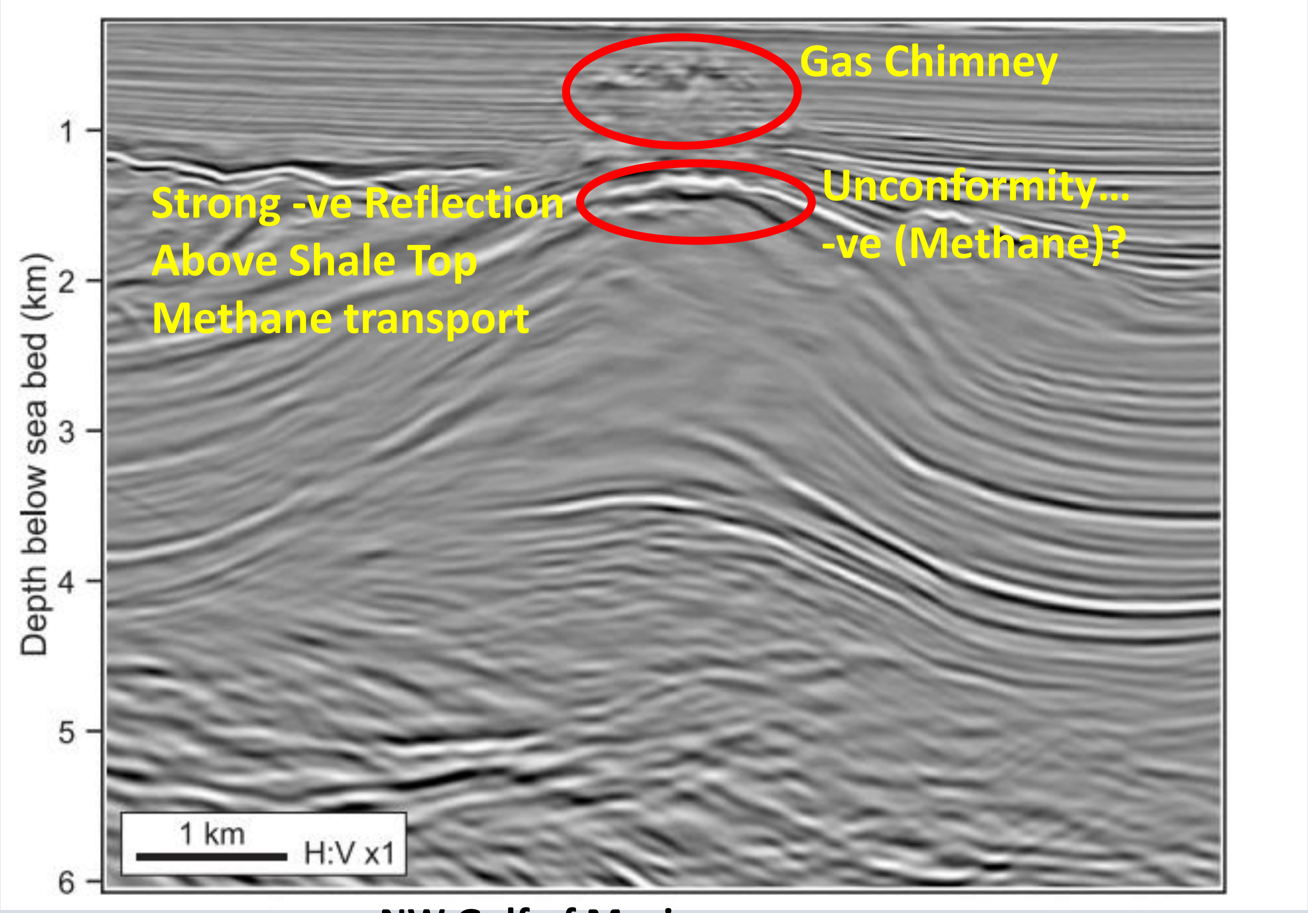


Seismic Expressions

Fold Cored mobile shale

- Mobile shale thickens towards the core
- Fluids and gases go across the unconformity
- In other places, no clear negative… gradational changes in overpressure

DHI: Direct Hydrocarbon Indicator

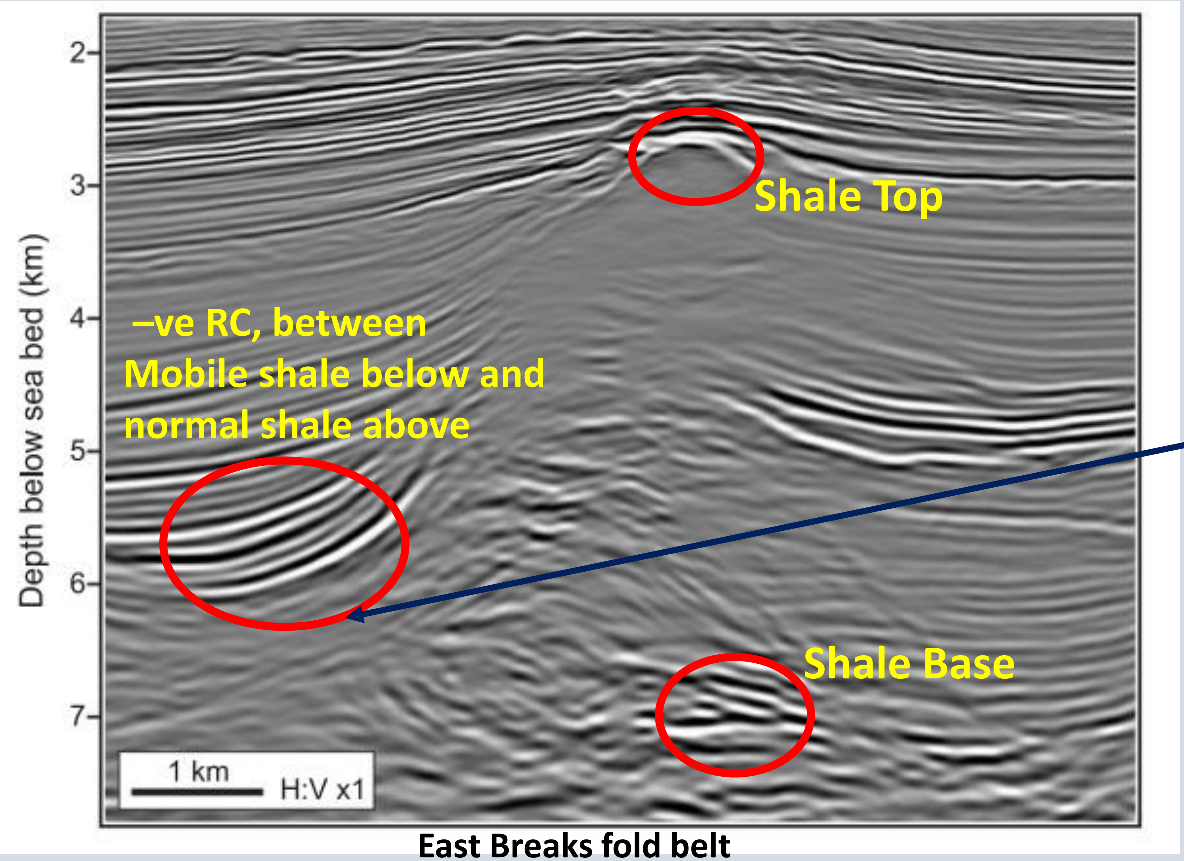


NW Gulf of Mexico

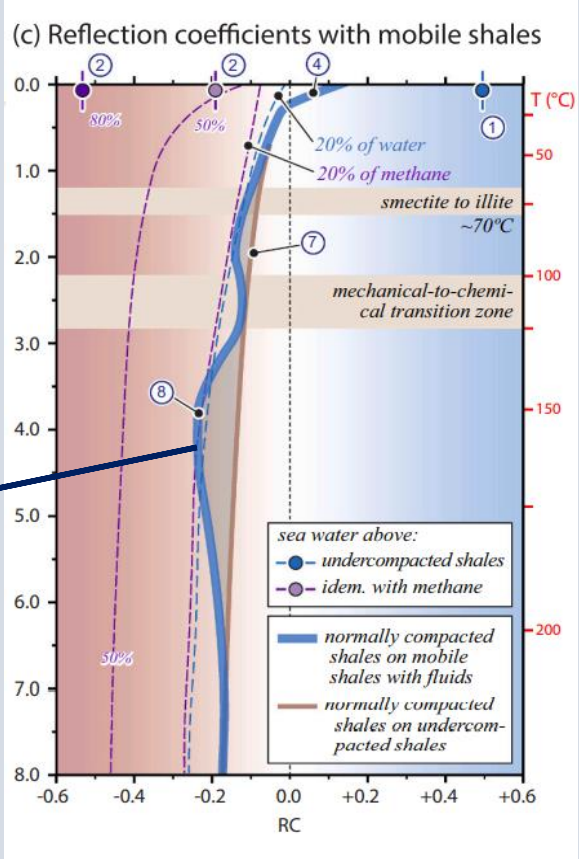
Seismic Expressions

Mobile shales in depth

- Negative reflectivity at top of shale….Methane rich fluids
- A positive reflection makes sense for overpressured, mobile shale above normally pressured sandstones and shales



East Breaks fold belt



Conclusions

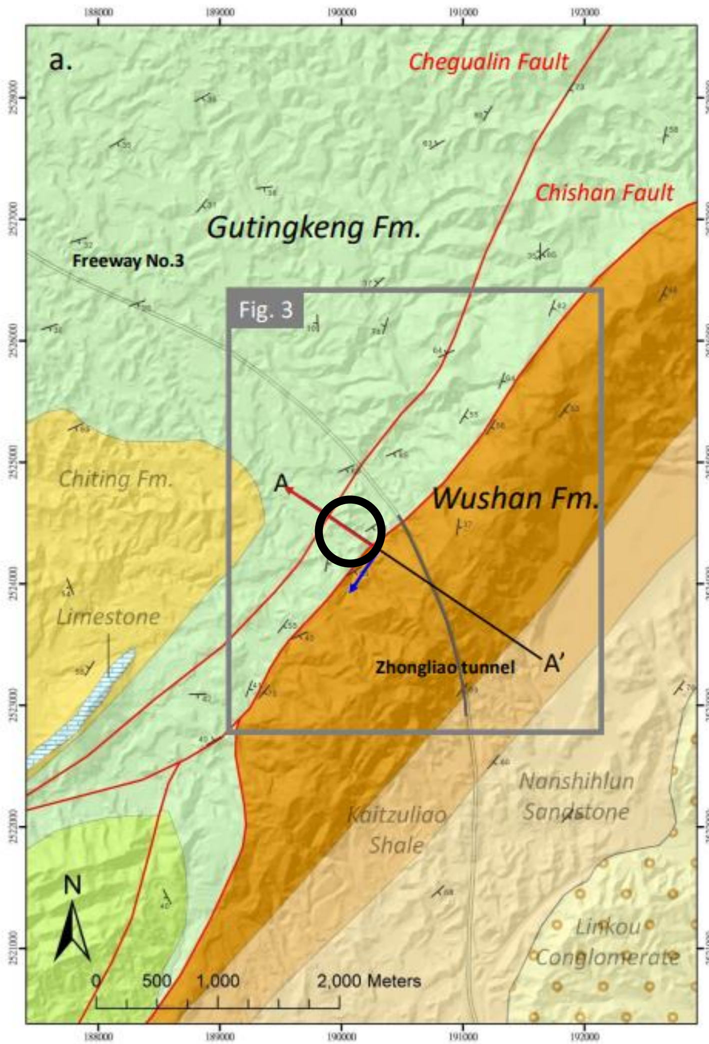
- Mobile shales represent the highly overpressured state of shales that pierce through its overlying roof of rocks in the earth crust.

- Illitization expels water and oil cracking generates methane in the depths around 1-2 Km and 2-5 Km, respectively.

- Fluid-gas mixtures characterize the shale with lower sonic velocity, density and acoustic impedance that tends to form criteria for its recognition on the seismic images.

- Careful evaluation of shale composition, thermal and burial histories and advanced seismic processing are prerequisite for a better understanding of mobile shales.

Future Work



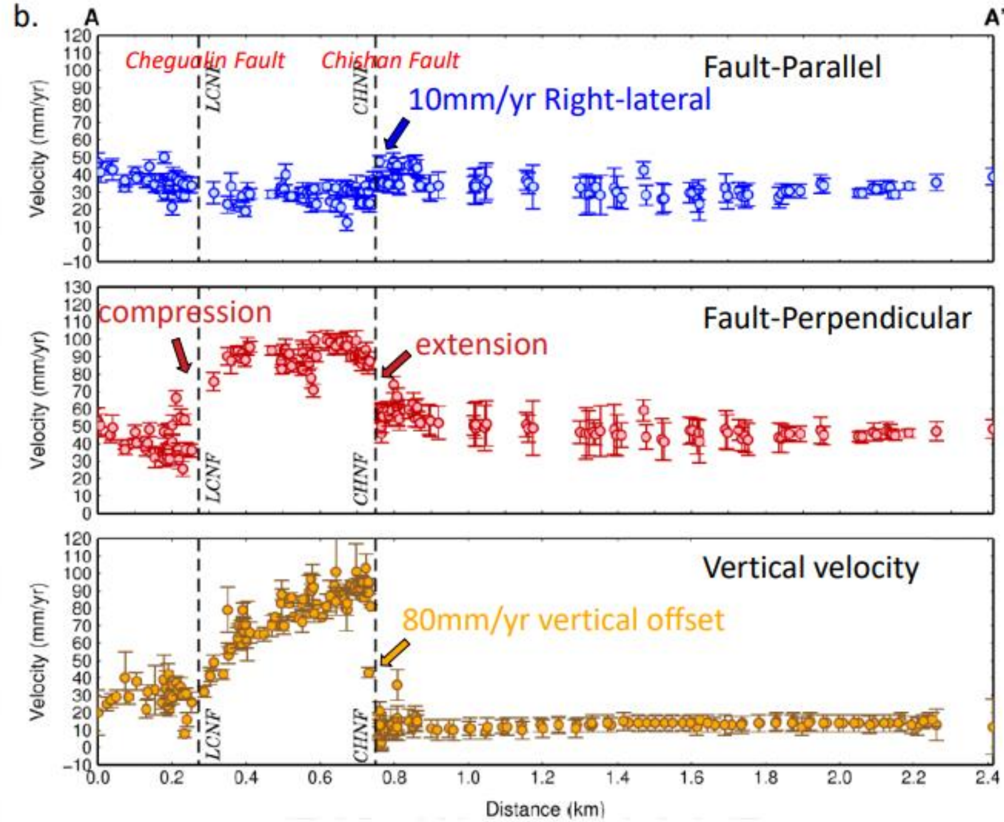


Fig. 1 (a) Geological map of Zhongliao tunnel area (Lin CW, 2013, complemented with our observations along the Chishan fault). (b) Velocity relative to Penghu based on geodetic measurements, projected on AA' line (Chang-Lee, 2014).

Courtesy of Chen Kai-Fong

THANK YOU

Any Questions?