Lithofacies and Depositional Environments

Review of Ch 2-4~ 2-10

Rock Physics Seminar, Mar.6th

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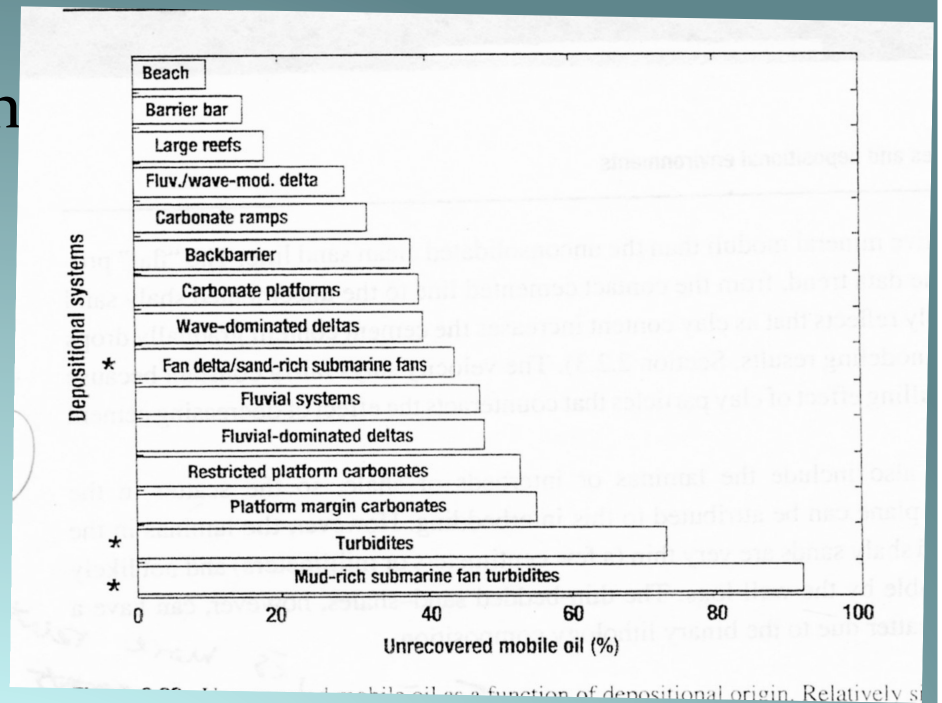
Outlines

- Introduction
- Facies and depositional environments
- Rock Physics analysis of seismic lithofacies
- Compaction of sands and shales
- Modeling velocity-depth trends
- Rock physics model constrained by local geology
- Conclusion & Discussion

Introduction

- Facies is defined as a rock unit with distinctive lithologic features. (i.e. compaction, grain size, bedding and so on.
- Establish a link between rock physics and sedimentology
- Facies have a major control on depositional geometries and porosity distributions and can be linked to pattern sedimentary process.
- Facies helps us to link physical properties to data acquisition



Walther's Law of facies

- When a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another.

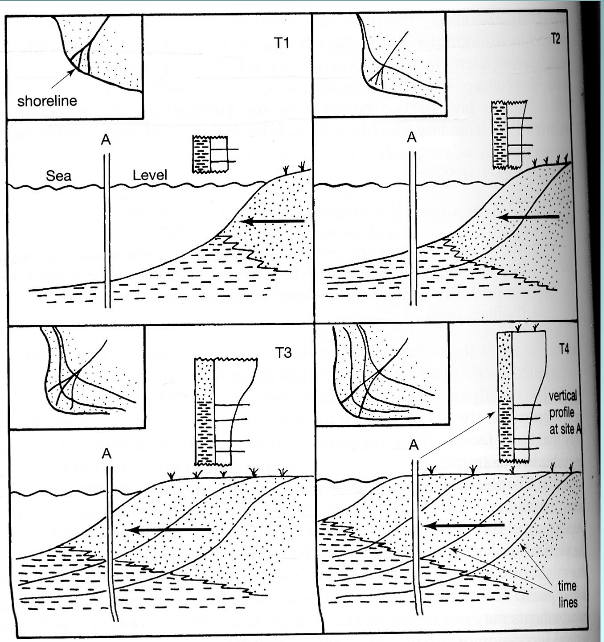


Figure 13.12
Walther's Law illustrated by the growth of a delta through time. Note the successive outbuilding of the delta at four different time periods (T1-T4). With time, the shoreline progrades from right to left, so that at a single location depicting a vertical succession (A), a gradual transition from prodelta mud to coarser-grained delta deposits takes place, generating a coarsening-upward succession. [After Pirrie, D., 1998, Interpreting the record: Facies analysis, *in* Doyle, P., and M. R. Bennett (eds.), Unlocking the stratigraphical record: Advances in modern stratigraphy, John Wiley and Sons, Ltd., Chichester, reproduced by permission.]

- No break in the sedimentary sequence
- Sedimentary sequence continues
- The concept of vertical deposition environment
- Shows the figure in the book

[Sam Boggs, Jr.}

Facies and depositional system

- North Sea turbidite system at seismic scale
- Facies I and VI vary their sand-shale ratio

Table 2.2 *Geological description of seismic lithofacies in North Sea deep-water clastic systems*

Facies	Geological description of facies and subfacies	Gamma-ray log motif
I *Gravels and conglomerates*	Gravels, conglomerates, and pebbly sands. *Sand-rich or mud-rich debris flow* deposits.	Complex. Can be blocky if *"clean"*
II Thick-bedded sandstone	IIa: Very clean, well-sorted, massive sandstones with small amounts of quartz overgrowths. Water-escape structures are common. Clay content less than 10%.	Usually blocky and smooth
	IIb: Clean, massive sandstones with clay coatings. Water-escape structures are prominent. Pore-filling clay content slightly higher than in Facies IIa (approximately 10–15%).	Bell and funnel shape, can occur [illegible]
	IIc: Plane-laminated sandstone. Higher pore-filling clay content (10–20%) and grain size in general smaller (fine- to medium-grained) than in Facies IIa and IIb.	Low, but increasing GR values, from IIa–IIc
	IId: Shaly sandstone (clay content between 20–40%).	• Intermediate in IId
III Interbedded sandstone –shale	Interbedded sand–shale couplets, where sand units are relatively thin-bedded compared with Facies II types of sand (i.e., below seismic resolution).	Serrated Intermediate GR values
IV Silty shales	Silty shales and thin-laminated silt–shale couplets. (In rock physics often referred to as "sandy" shales.)	Serrated High GR values
V Pure shales	Pure shales, often seen as thick, massive shale units.	Serrated/smooth Very high GR values
VI Chaotic deposits	Syn-depositional deformation units, slide blocks, slump deposits, injection sands, shale diapirs, etc.	Serrated/complex

IIa: Consolidated clean sand
IIb: Unconsolidated clean sands
IIc: Plane-laminated sand
IId: Shaly sand

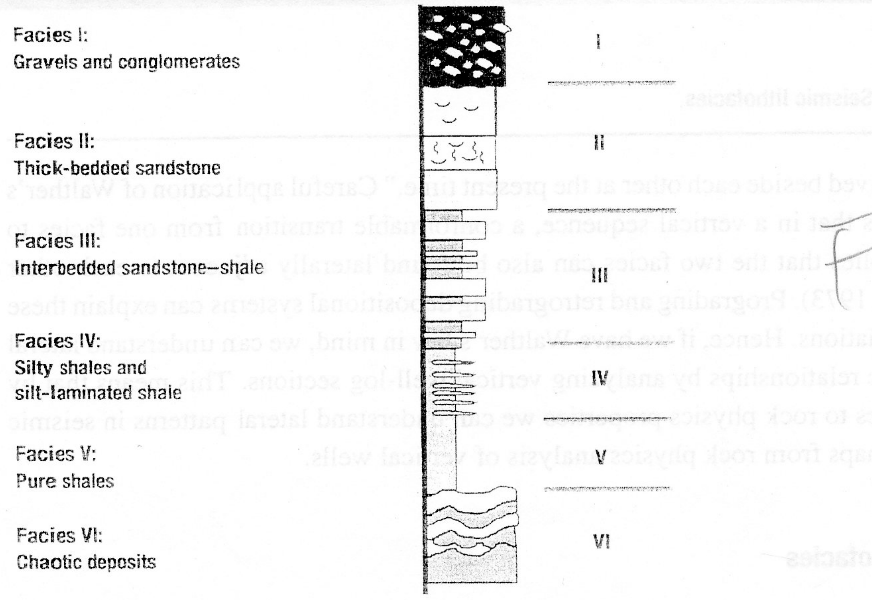


Figure 2.29 Seismic lithofacies in deep-water clastic systems. Geologic description.

Clay content (Sand-Shale relations)

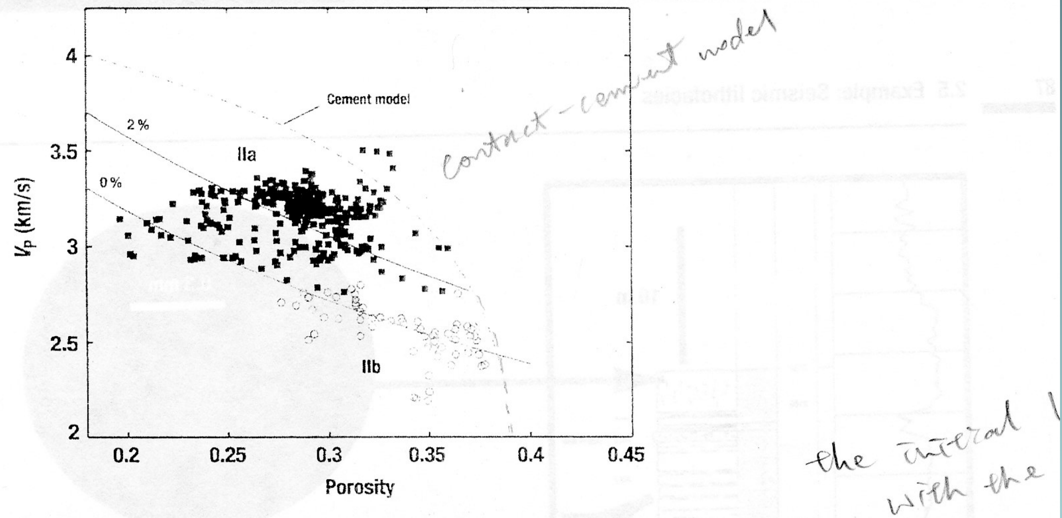
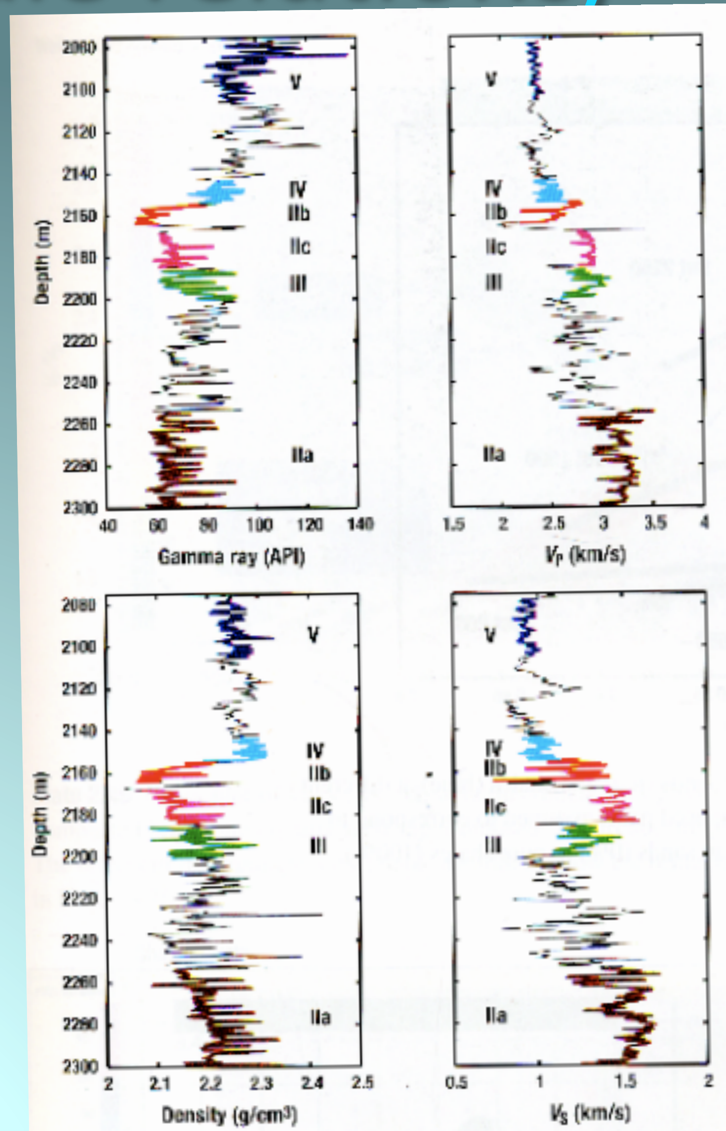


Figure 2.33 Rock physics diagnostics of two sandstone intervals in the type-well, indicating an unconsolidated zone (Facies IIb, open circles) and a cemented zone (Facies IIa, filled squares). The unconsolidated sands have been confirmed by core observations (Figure 2.32). Presence of cemented Heimdal Formation sands has been confirmed in Section 2.3.



Sand-Shale plotting

IIa: Consolidated clean sand
IIb: Unconsolidated clean sands
IIc: Plane-laminated sand
IId: Shaly sand
III : Interbedded sand-stone
IV: Silty shales
V: Pure shales

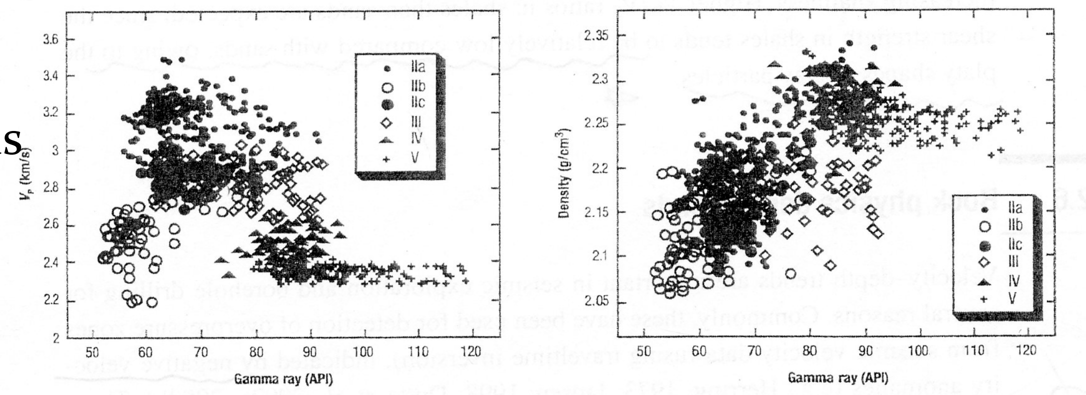


Figure 2.34 P-wave velocity versus gamma ray (left) and density versus gamma ray (right), for different seismic lithofacies in training data (i.e. Well 2). Note the ambiguity in P-wave velocity between Facies IIb and IV/V.

IIb = unconsolidated sand Ambiguity can be distinguished by V. Density-ρ has no ambiguity.

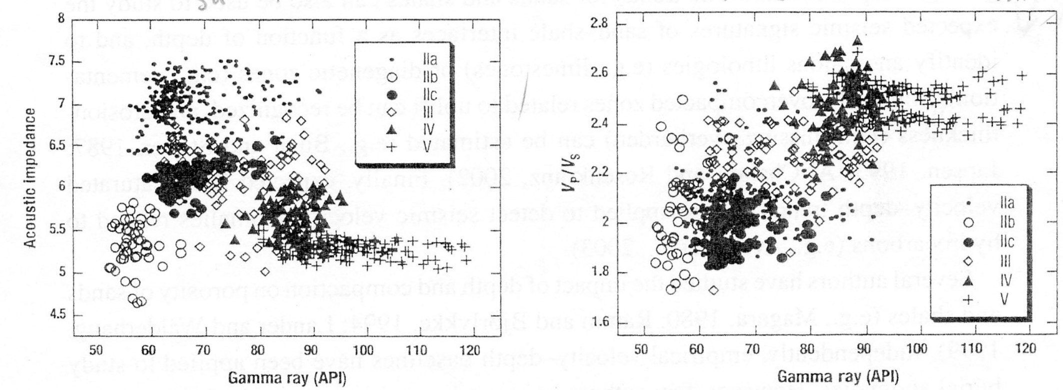


Figure 2.35 Acoustic impedance versus gamma ray (left) and V_P/V_S ratio versus gamma ray (right) in type-well.

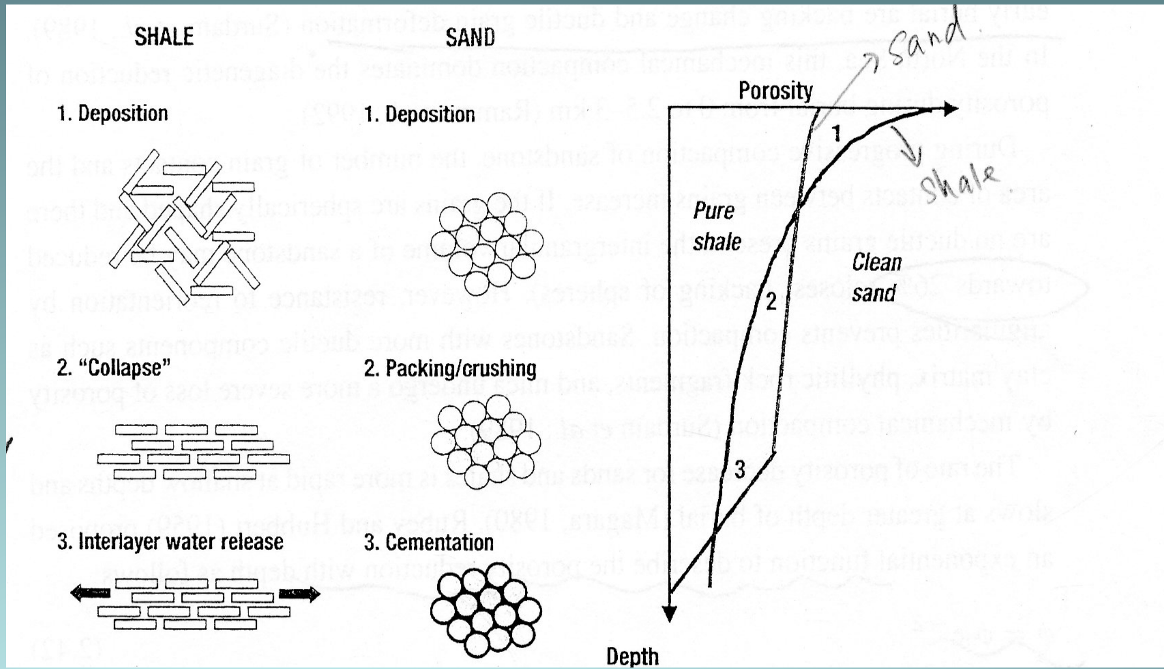
ρV.

Rock physics depth trend

Empirical porosity & depth trend

Vp, Vs, density model

Distinguish frame properties from fluid properties



- Study velocity depth trend can be a tool to identify the anomalies which can indicate over-pressure zone/ over-compaction and different fluid saturation.

Compaction of Shales and Sands

- In the North Sea, mechanical compaction of sand dominated the diagenetic reduction of porosity for upper 3km
- Pure shale tend to obtain a nearly constant porosity trend vs. depth

$$\phi = \phi_0 e^{-cZ}$$

Mechanical compaction of sands & shales

$$Z=6.02\, N^{6.35}$$

Solidity vs. depth for shale

$$\phi = \phi_0 e^{-(\alpha+\beta C_1)Z} \qquad C_1 = \frac{V_{c1}}{V_{qz}}$$

Mechanical compaction of sands

$$Z=15\, N^{8}$$

Solidity vs. depth Tertiary shales of GOM

$$\phi = \phi_D - k(Z - Z_D)$$

Chemical compaction (clean sandstone)

$$Z=3.7\ln[0.49/(1-N)]$$

North Sea sandstone curve (rather mature)

Compaction of Shales and Sands

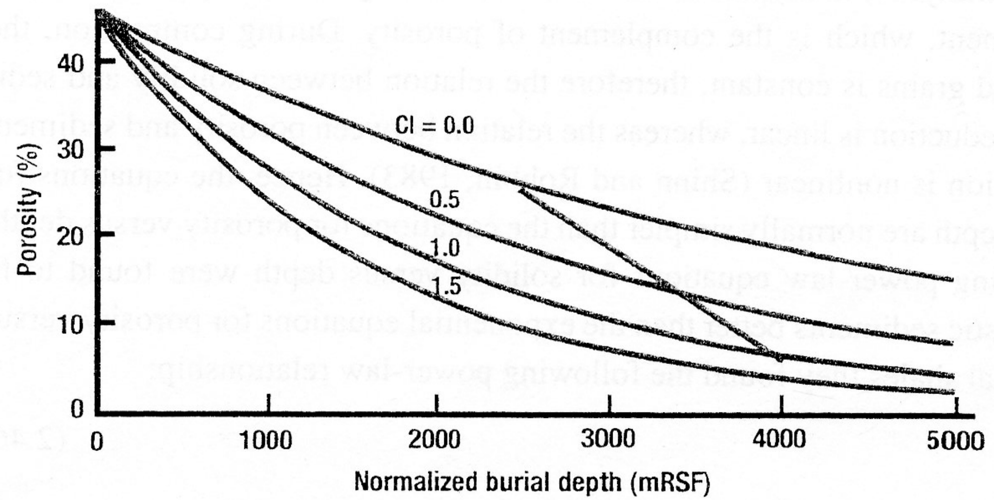


Figure 2.37 Sand and shale porosity models (equations (2.43) and (2.45)) with depth. During shallow burial, porosity change is mainly due to mechanical compaction (curved lines, equation (2.43)), and the porosity decreases with increasing clay content (i.e., increasing ductility). At a certain depth level, clean sands lose porosity mainly via pressure solution and quartz cementation (straight line, equation (2.45)). (Modified from Ramm and Bjørlykke, 1994.) Depth is in meters relative to sea floor (mRSF).

Rock Physics Template

Temperature, pressure, fluid reference density

(Environmental control)

Vp, Vs, density model

Distinguish frame properties from fluid properties

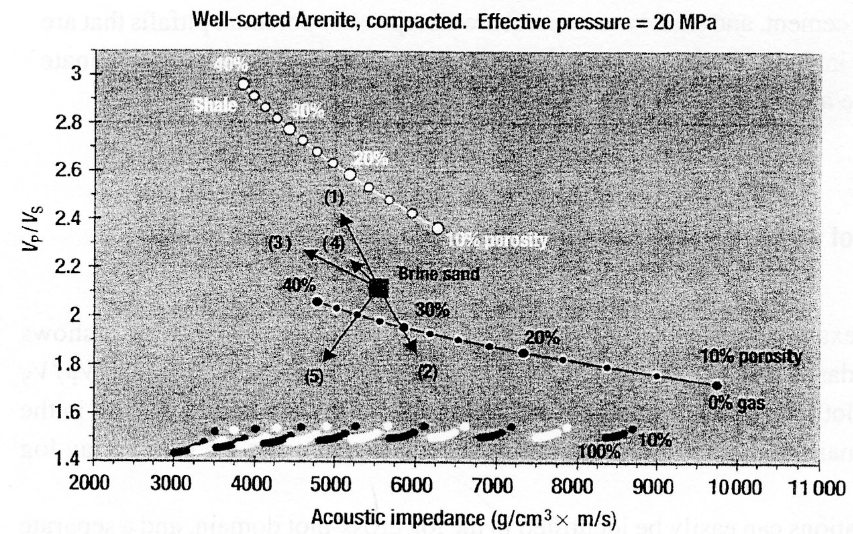


Figure 2.46 A rock physics template (RPT) presented as cross-plots of V_P/V_S versus AI includes rock physics models locally constrained by depth (i.e., pressure), mineralogy, critical porosity, and fluid properties. The template includes porosity trends for different lithologies, and increasing gas saturation for sands (assuming uniform saturation). The black arrows show various geologic trends (conceptually): (1) increasing shaliness, (2) increasing cement volume, (3) increasing porosity, (4) decreasing effective pressure, and (5) increasing gas saturation.

Pitfall: maybe over simplified for instance, calcite cement and shallow overpressure and so on

Rock Physics Templates

Shale A and Shale B have different porosity

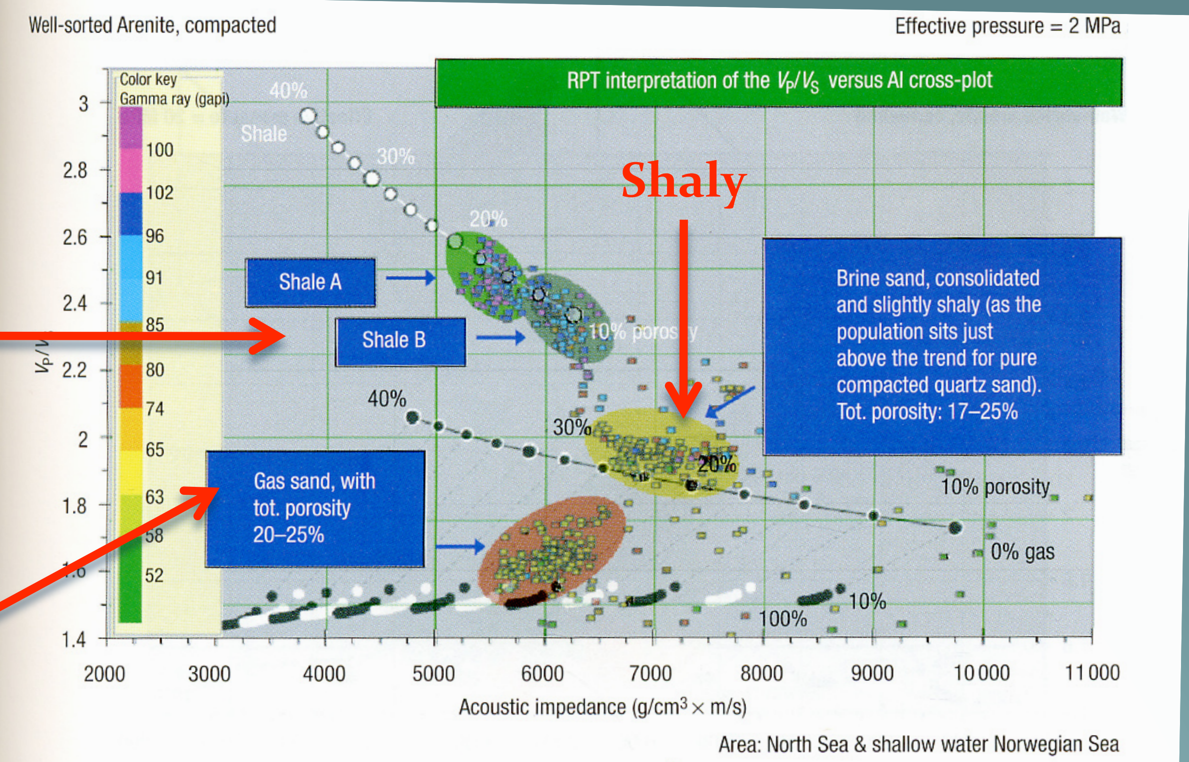


Plate 2.48 Cross-plot of V_P/V_S vs. AI, with theoretical rock physics trends for pure shale and clean compacted brine-filled quartz sand superimposed. The trends are plotted as functions of the total porosities. The effects of different gas saturations are added below the brine-sand trend. The color-coding is the same as in Plate 2.47.

Conclusions & Discussions

- For sands, there are ambiguities between clay content and sorting (S-wave info will help)
- Potential resolution different between well-log and seismic
- Separate depth-related changes (rock frame compaction) and constant-depth variations (fluid)
- Deviation from expected velocity –depth trends can be related to overpressure, gas, diagenesis, lithology, uplift, etc.