Diagenetic reactions during deep burial in sedimentary basins. Consequences for differential stresses.

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What is HPHT Reservoirs?

Temperature > 140-150 C ?

Fluid pressure > 50 MPa ?
With over pressure? 100 MPa ?

Requirements :
Preservation of porosity at great depth due to retarded quartz cementation(clay coatings micro quartz etc).

Cap rock integrety : Slightly permeable cap rock or lateral drainage.
In most cases the quality of sandstone reservoirs reaches critical values at about 4 Km depth (130 °C)

HPHT are exceptions to the rules of normal diagenesis.
There is a reason why there is still sufficient porosity at great depth and why there is still oil or gas in the reservoir.

The diagenetic processes are the same in all basins, but the sediment compositions and the temperature history vary greatly.

Haltenbanken - Effect of lateral drainage

V. Storvoll et al. / Marine and Petroleum Geology 19 (2002) 767–781

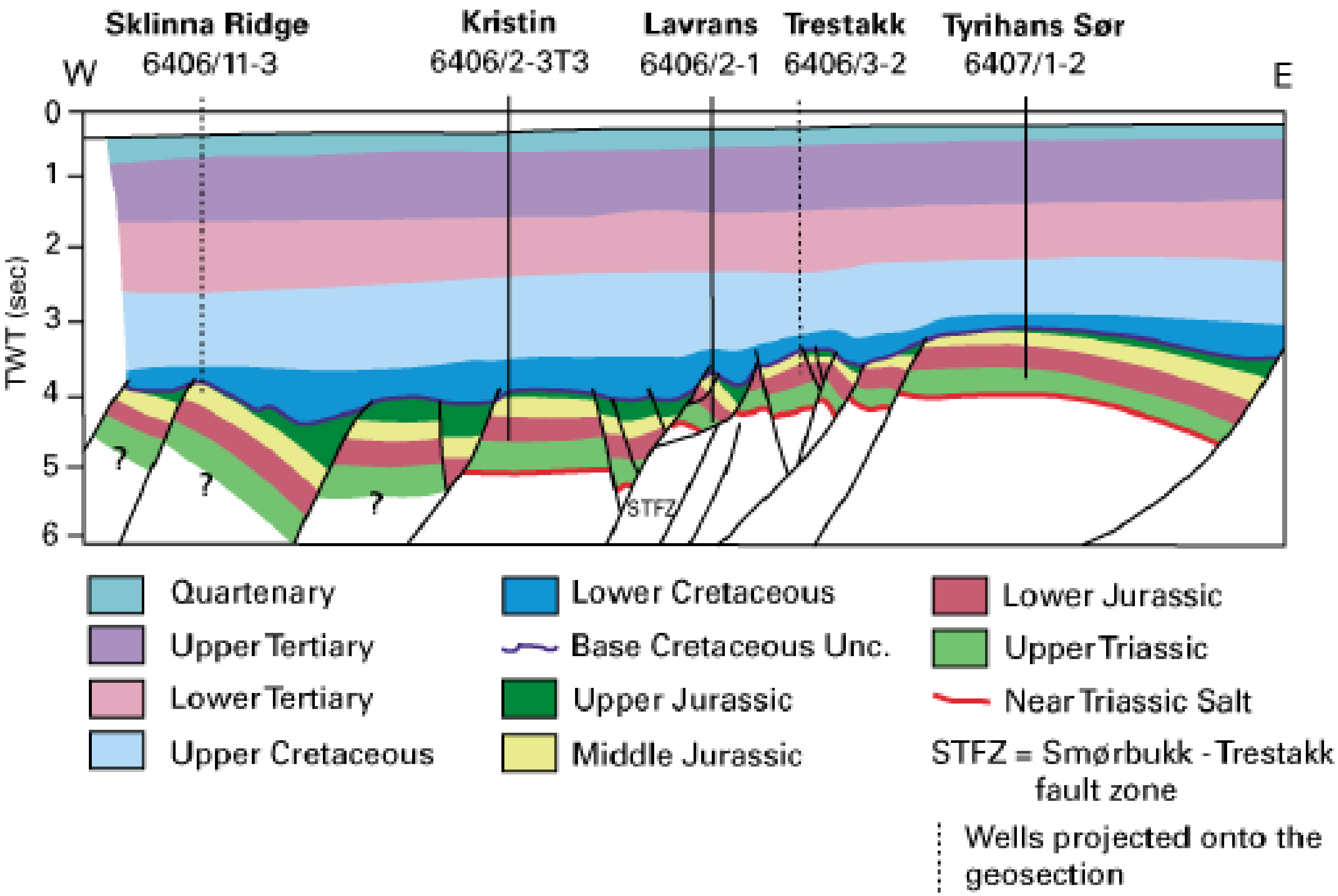


Fig. 3. Cross-section through the Halten Terrace. The position of the section is outlined in Fig. 1.

Kristin Field. Porosity preservation due to chlorite and illite coatings
Storvoll et al. 2002

V. Storvoll et al. / Marine and Petroleum Geology 19 (2002) 767–781 777

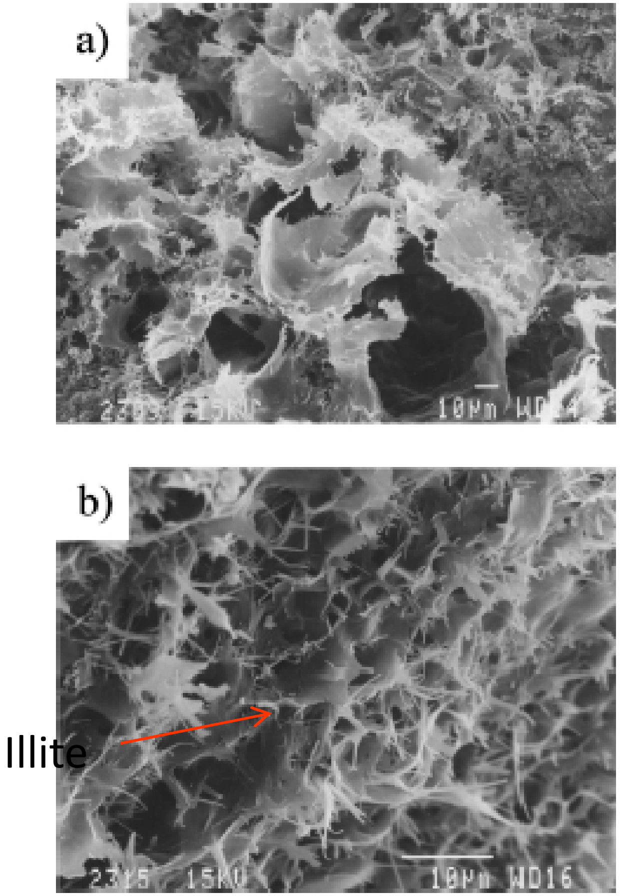


Fig. 9. (a) Illite with a corn flake morphology, which implies a smectite mixed layer clay precursor (Pollastro, 1985). Well 6406/2-3T3, 4670.8 m (core depth). (b) Illite with a more sheet like morphology compared to (a). Well 6406/2-3T3, 4701.5 m (core depth).

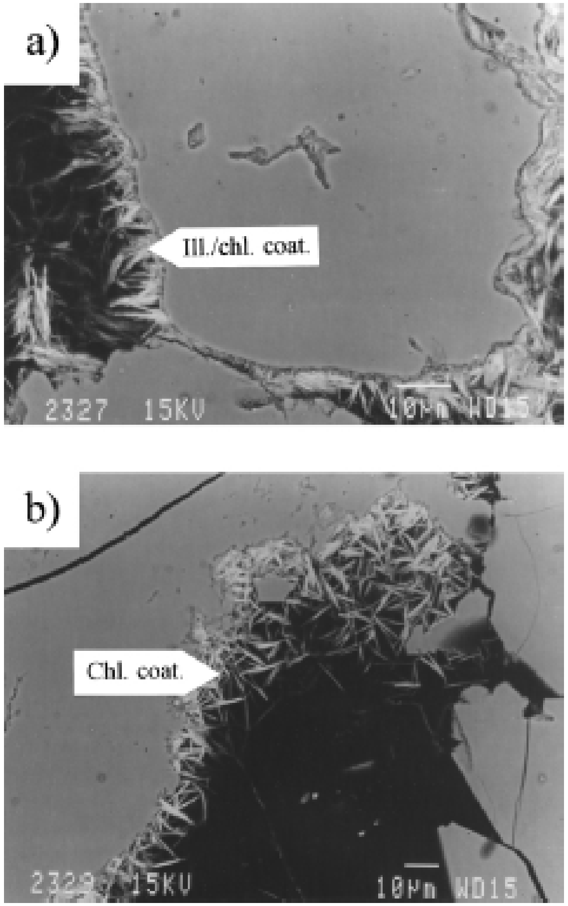
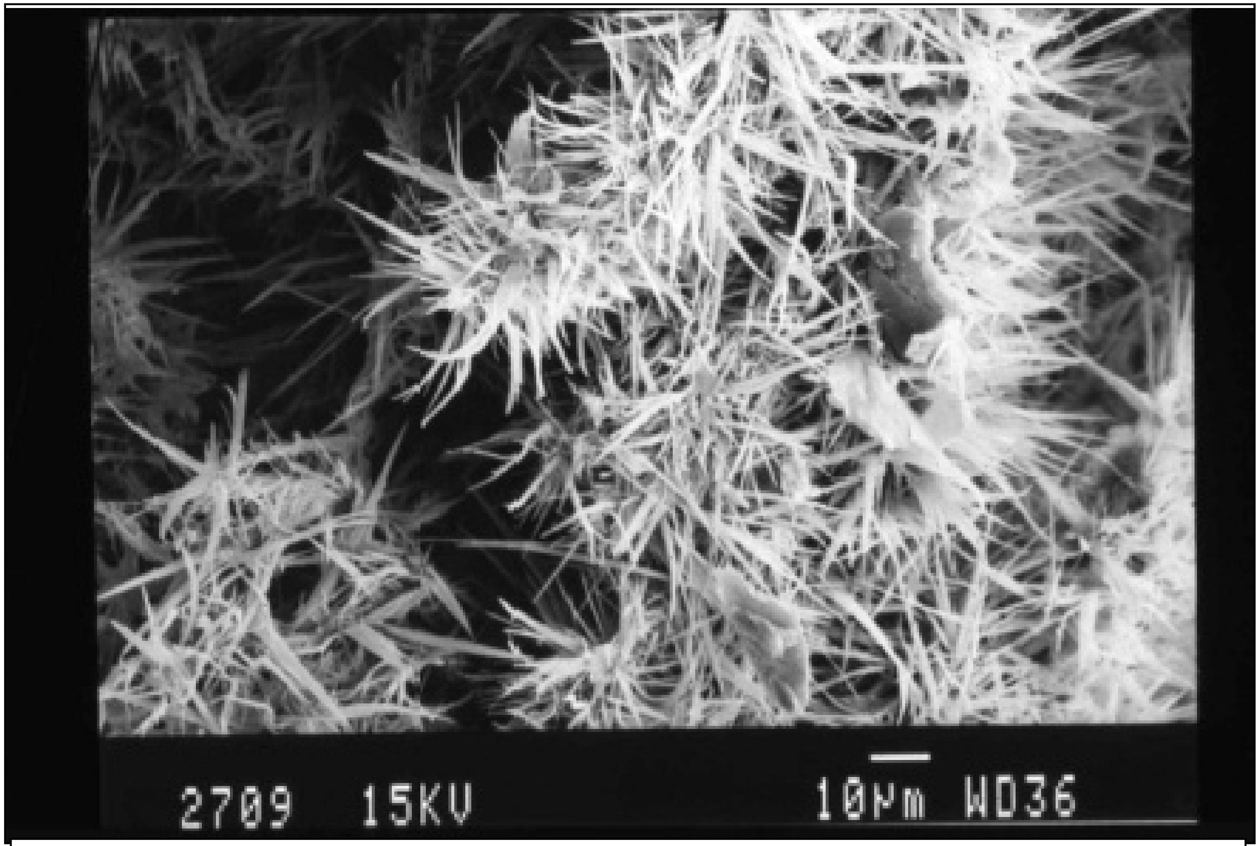


Fig. 10. (a) Coating of illite and chlorite (Ill./chl. coat.). Backscatter electron image. Well 6406/2-5, 4846.8 m (core depth). (b) Backscatter electron image of continuous chlorite coating (Chl. coat.). Well 6406/2-5, 4846.8 m (core depth).

Garn Fm.
4.8 km

Pore filling illite



Pore-filling authigenic illite from a Jurassic reservoir, Haltenbanken (4.2 km depth)

- kaolinite + K-feldspar = Illite + quartz + water (>130 °C)

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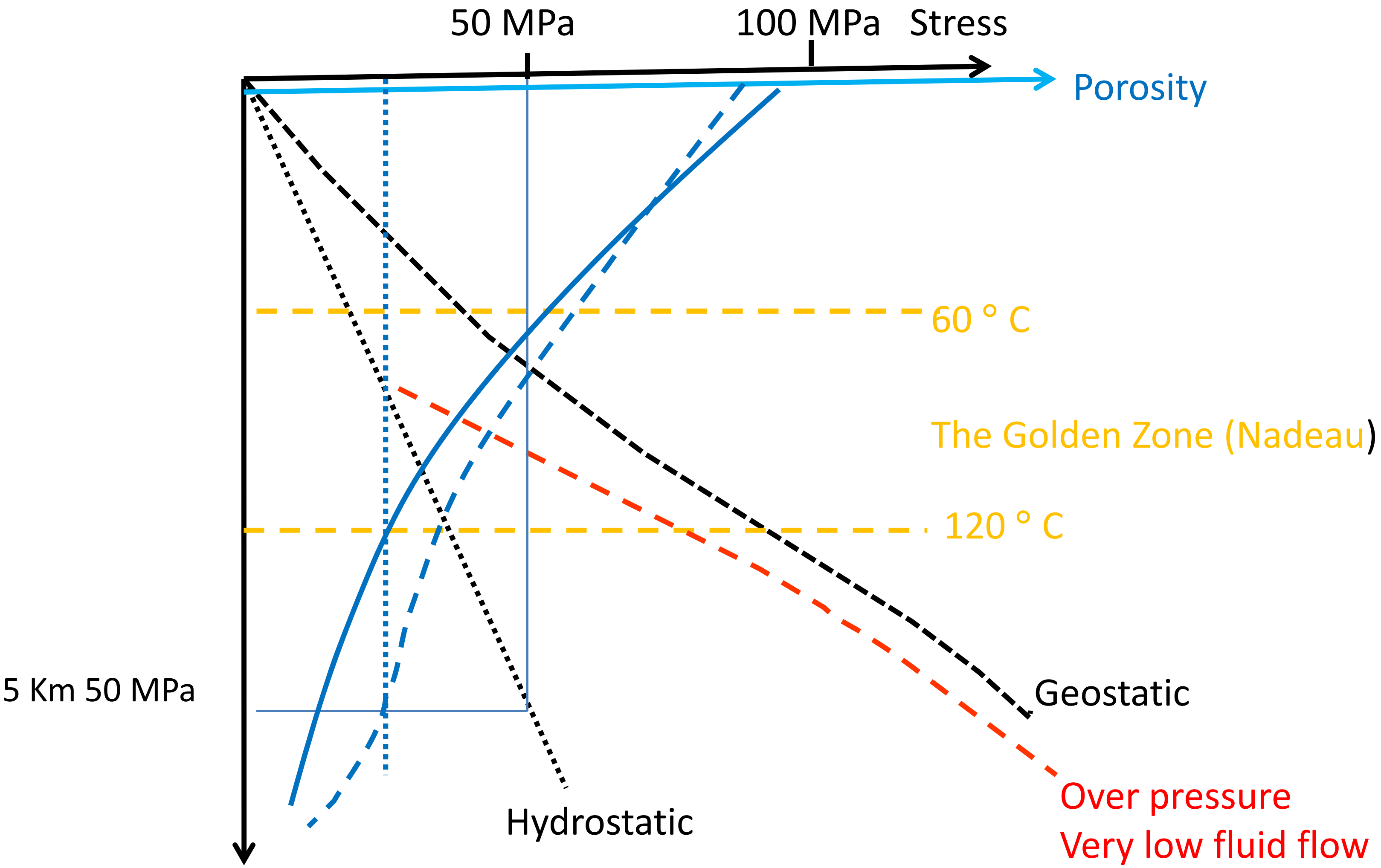
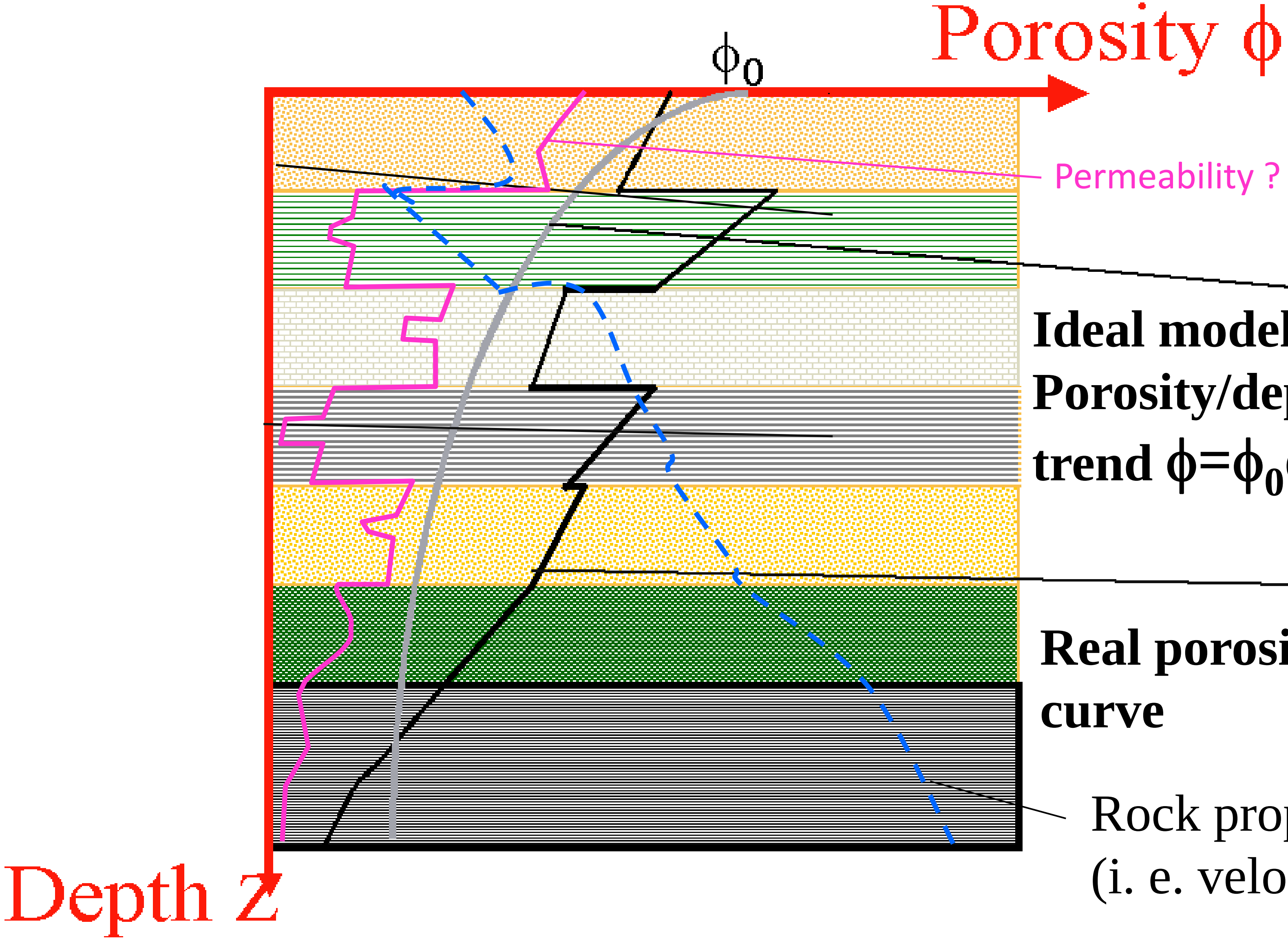


Over pressure
Very low fluid flow rates
. No convection.

Compaction of sedimentary layers with different initial composition.

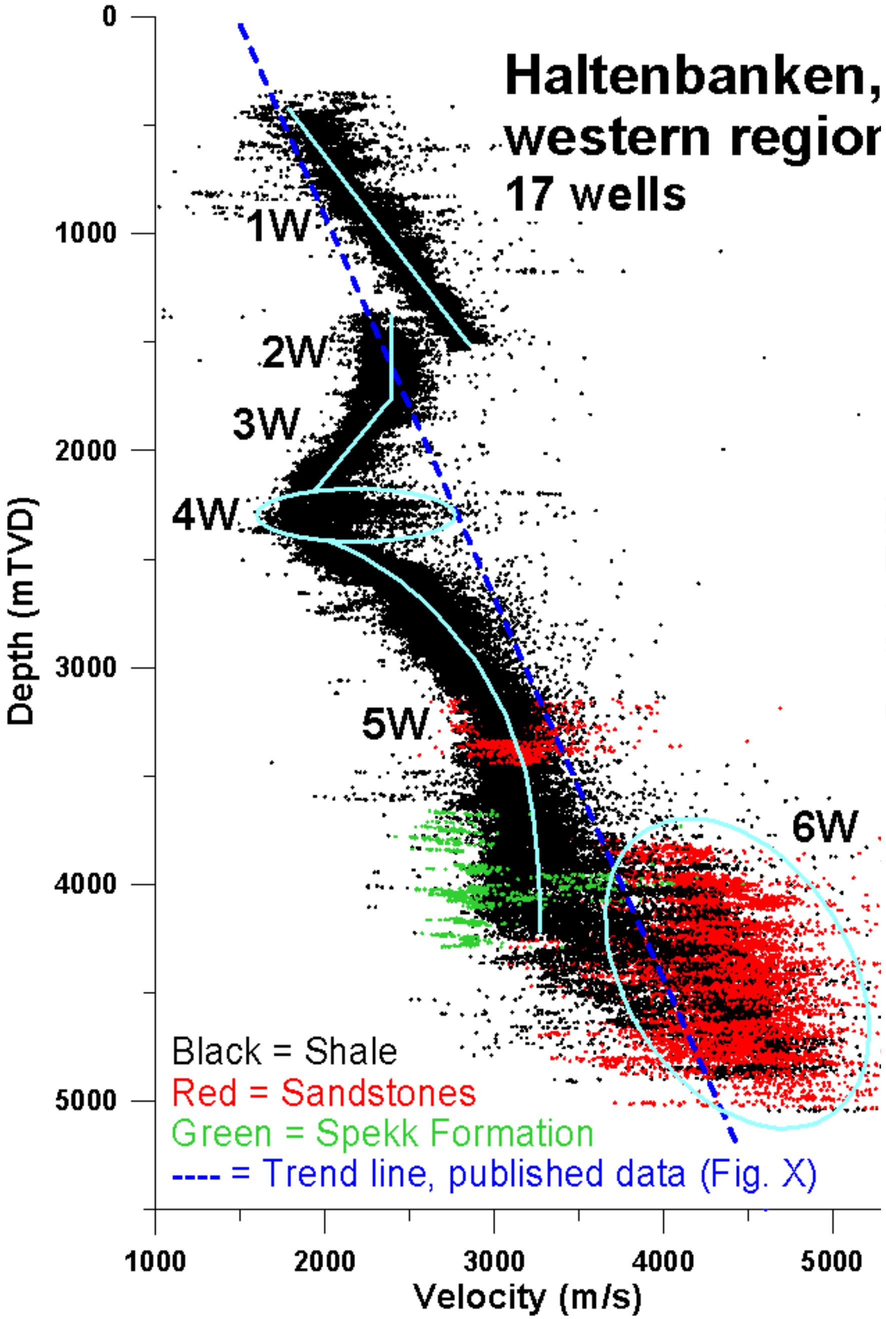


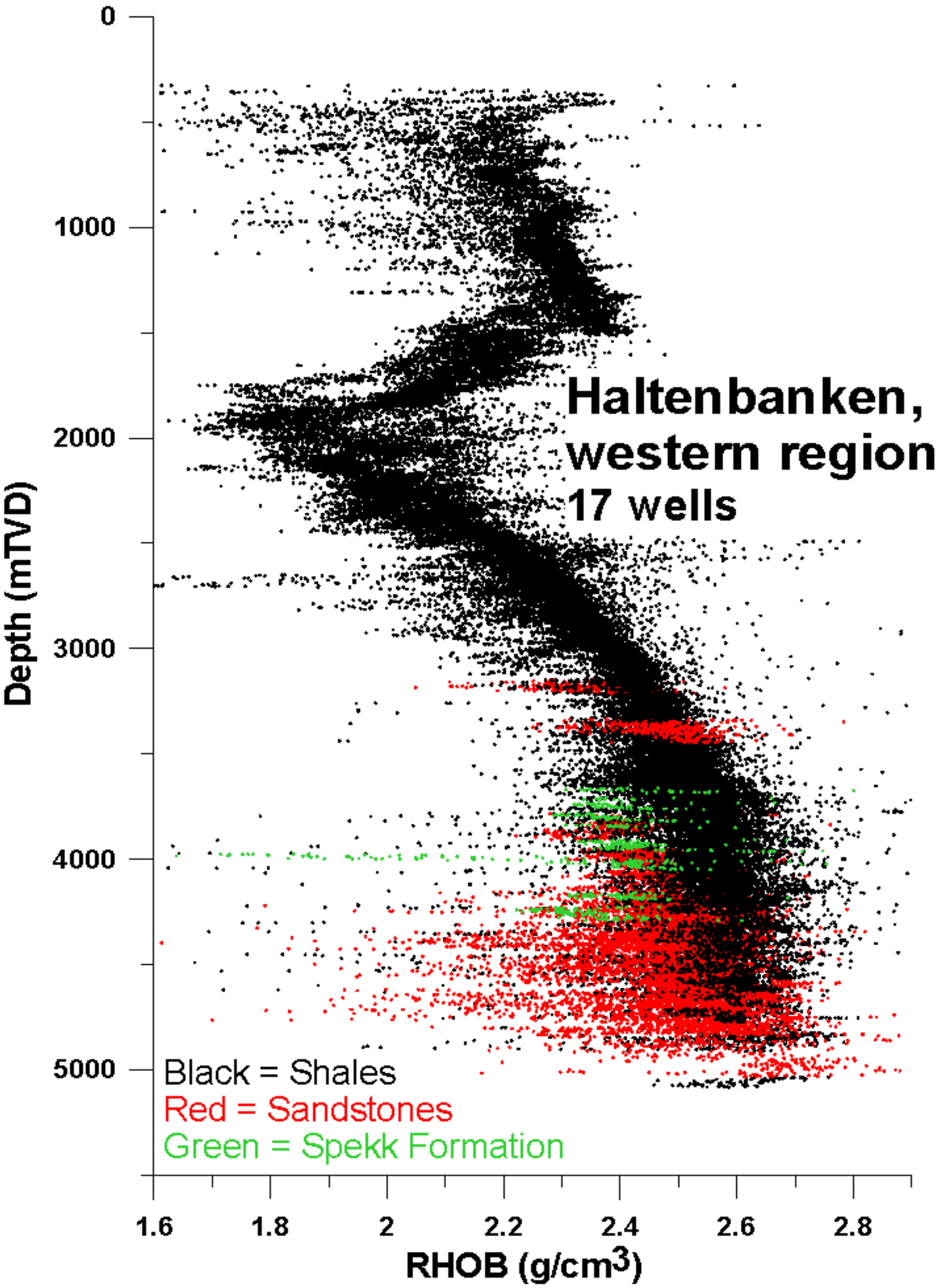
Permeability ?

Ideal modelled Porosity/depth trend $\phi=\phi_0 e^{-cz}$

Real porosity/dept curve

Rock properties (i. e. velocity)





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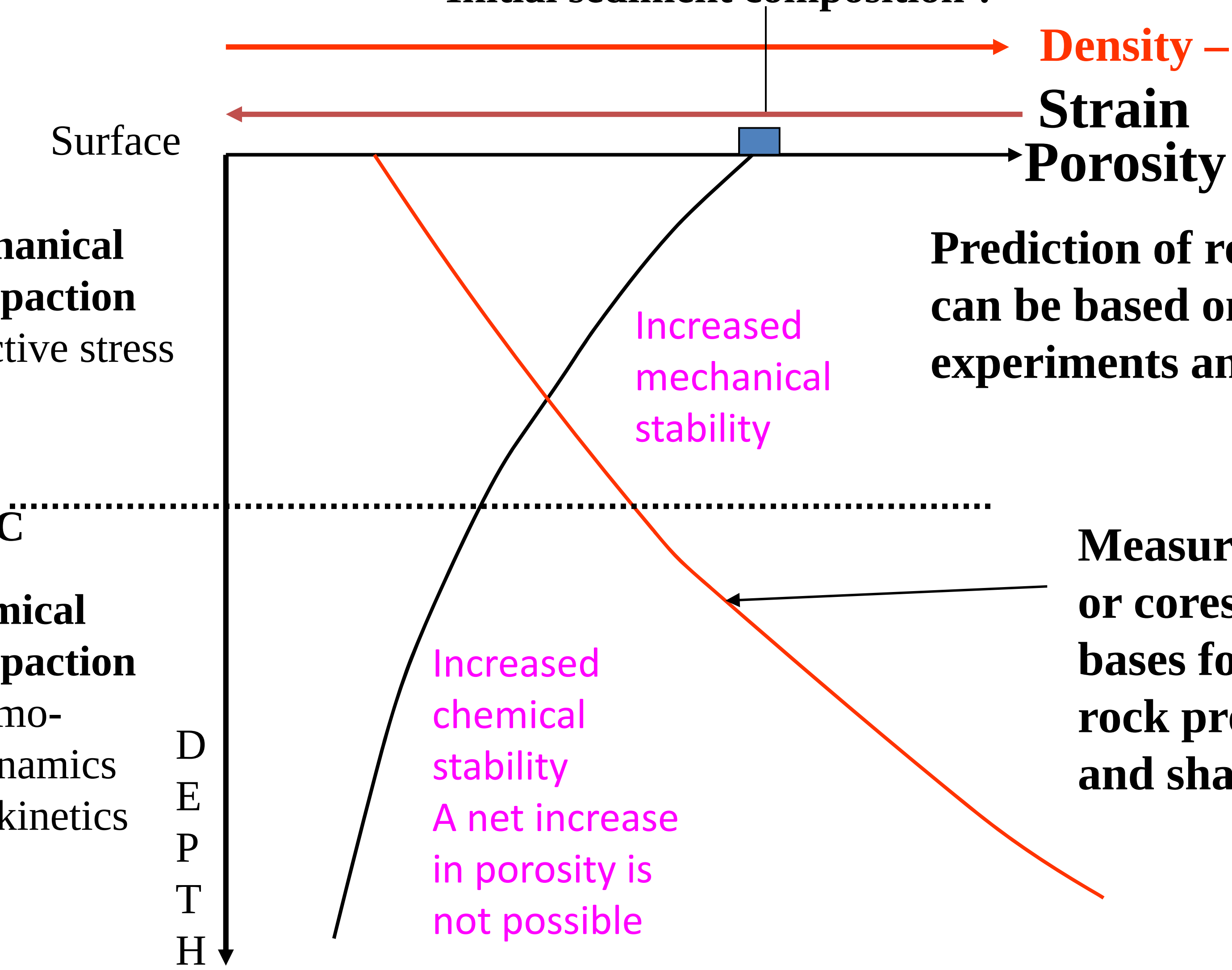
Storvoll et al., 2005; AAPG

Burial diagenesis - Compaction of silicious sedimenets



Initial sediment composition ?

Density – velocity (ampl.)

Strain

Porosity

Surface

Mechanical Compaction
Effective stress

Increased mechanical stability

Prediction of rock properties can be based on observations, experiments and modelling

70 - 100°C

Measurements from logs or cores provides a good bases for prediction rock properties at deeper and shallower depth

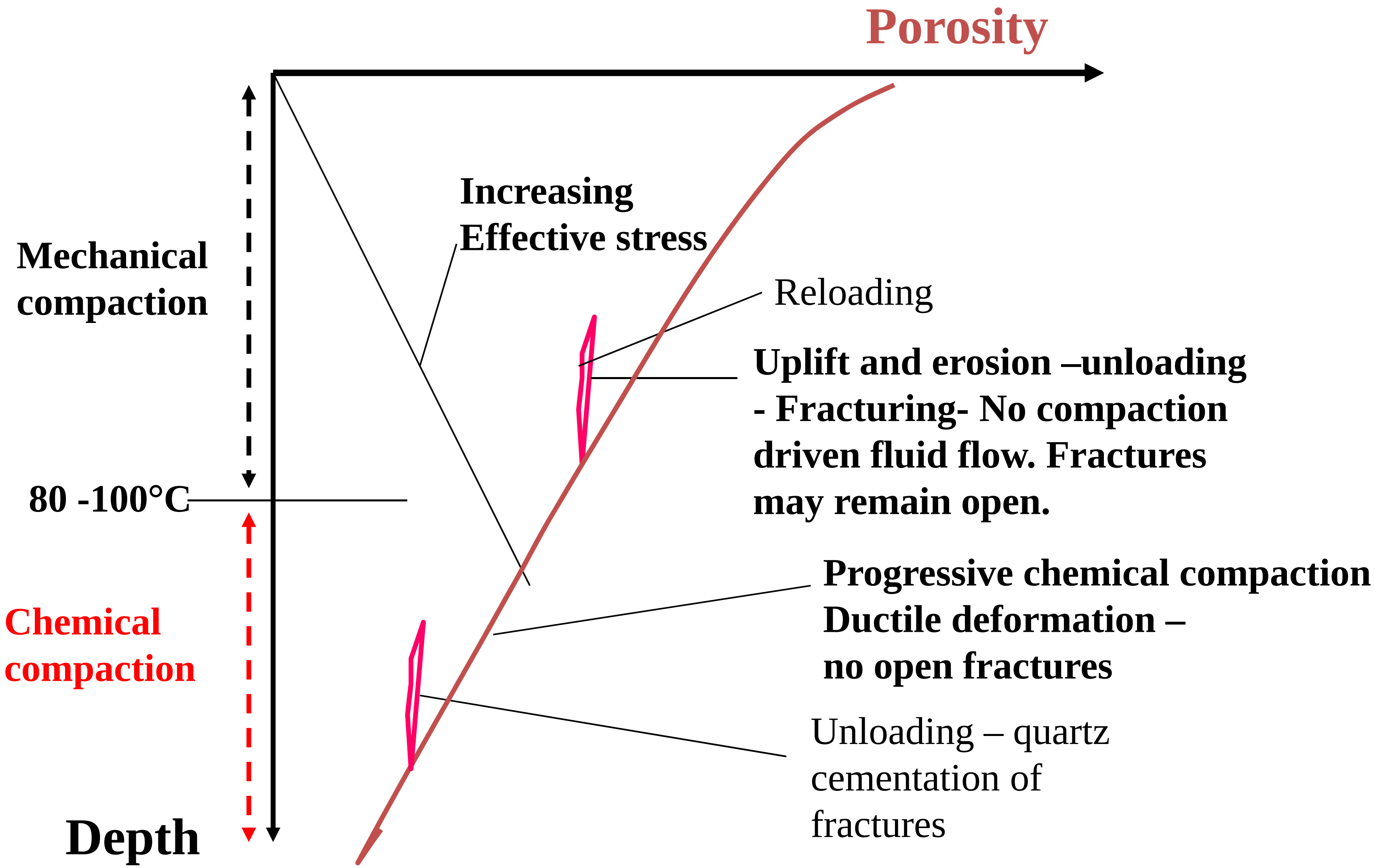
Chemical Compaction
Thermo-dynanamics and kinetics

Increased chemical stability
A net increase in porosity is not possible

DEPTH

Stress/Temperature

Mechanical and chemical compaction during progressive burial and uplift



Porosity

Increasing Effective stress

Mechanical compaction

Reloading

Uplift and erosion –unloading - Fracturing- No compaction driven fluid flow. Fractures may remain open.

80 -100°C

Progressive chemical compaction Ductile deformation – no open fractures

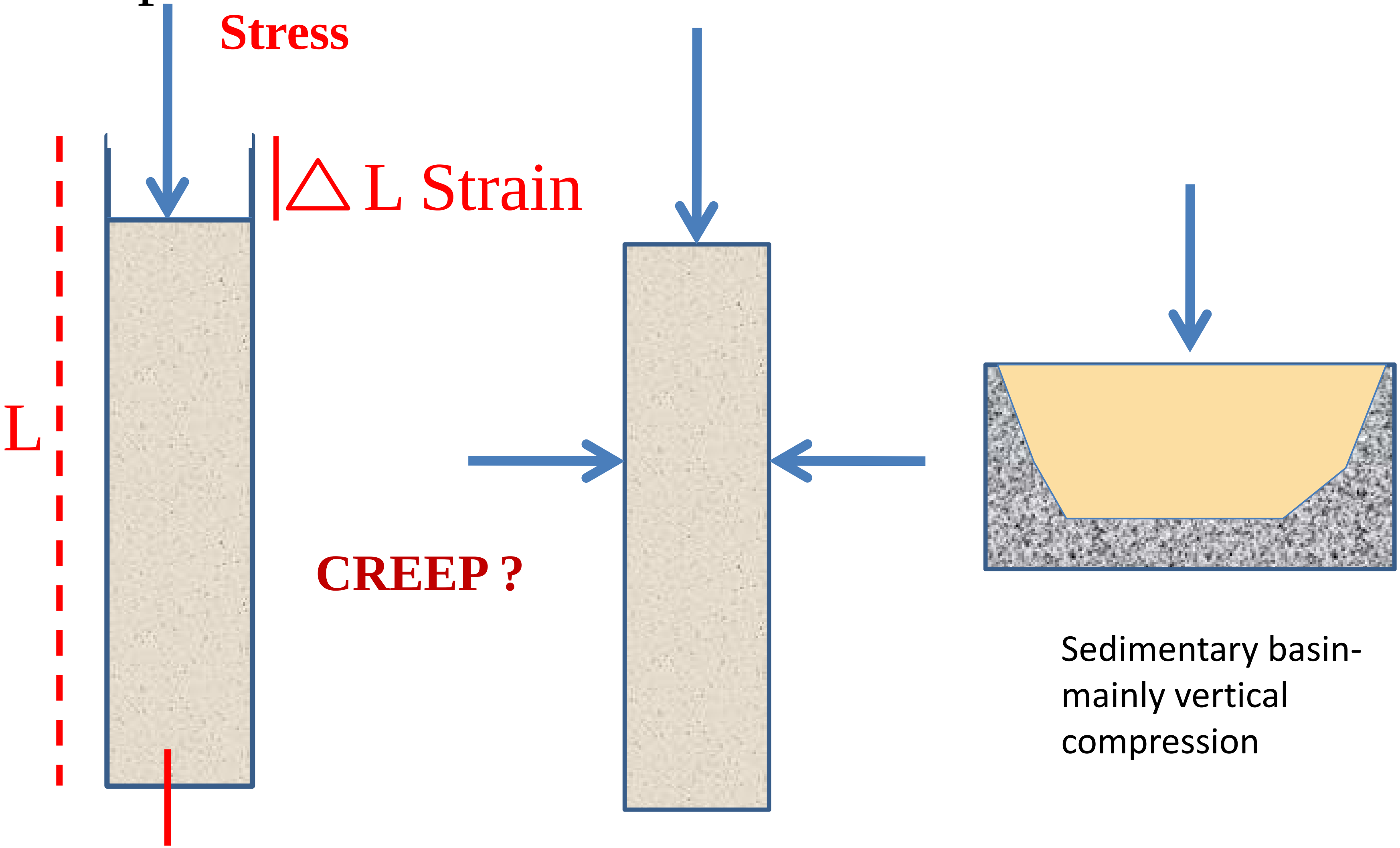
Chemical compaction

Unloading – quartz cementation of fractures

Depth

Experimental mechanical compaction

Compaction in Sedimentary basins



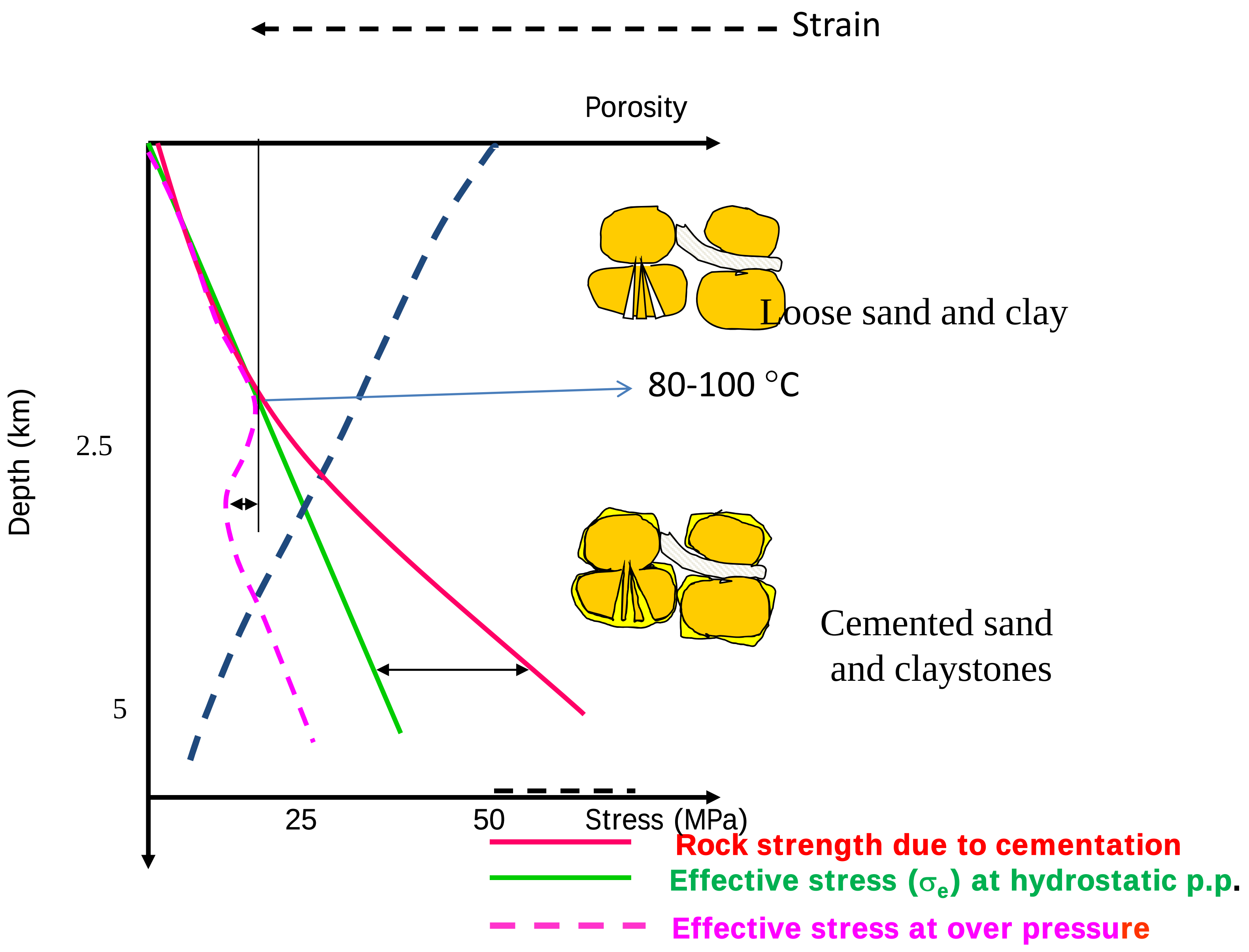
Fluid pressure control

Odeometer

Triaxial compaction

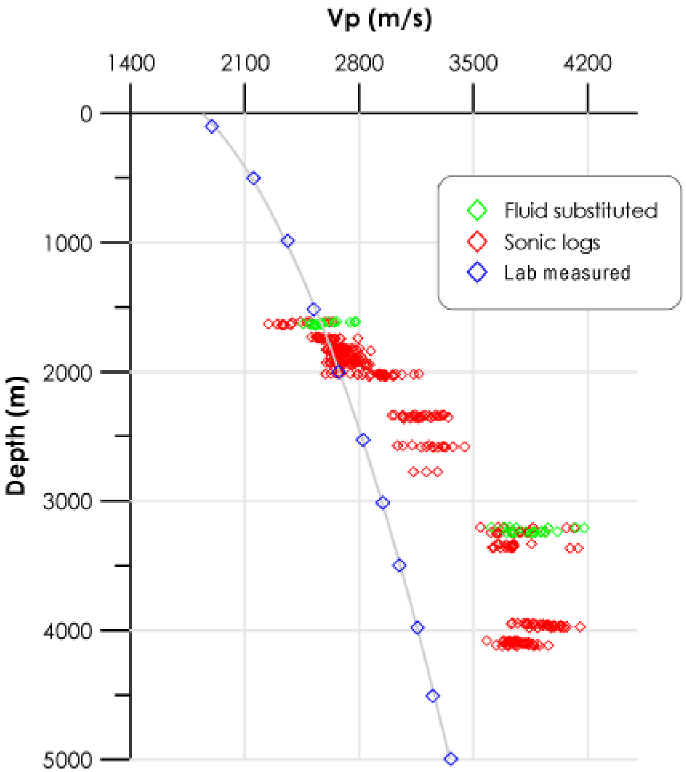
Sedimentary basin-
mainly vertical
compression

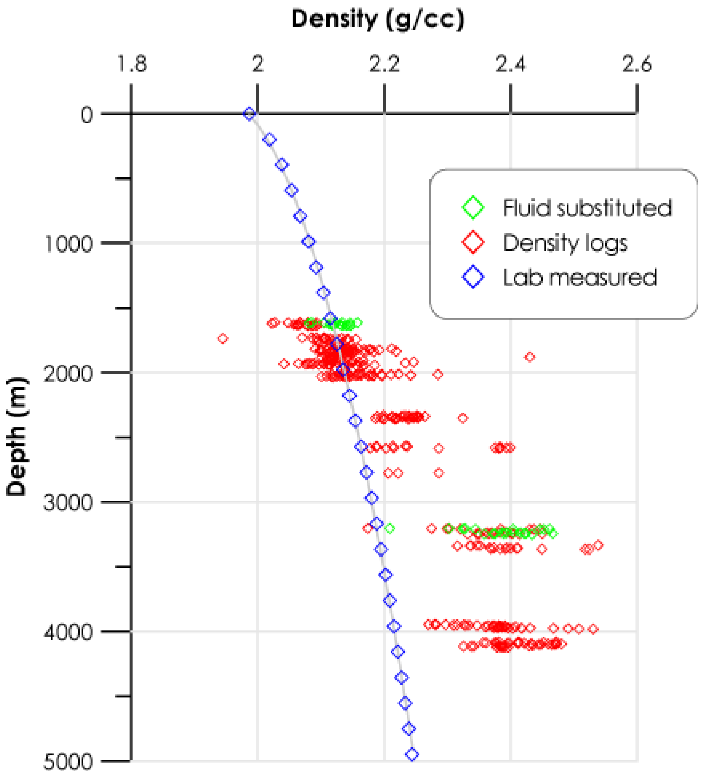
Compaction of Sand



Bjørlykke 2003

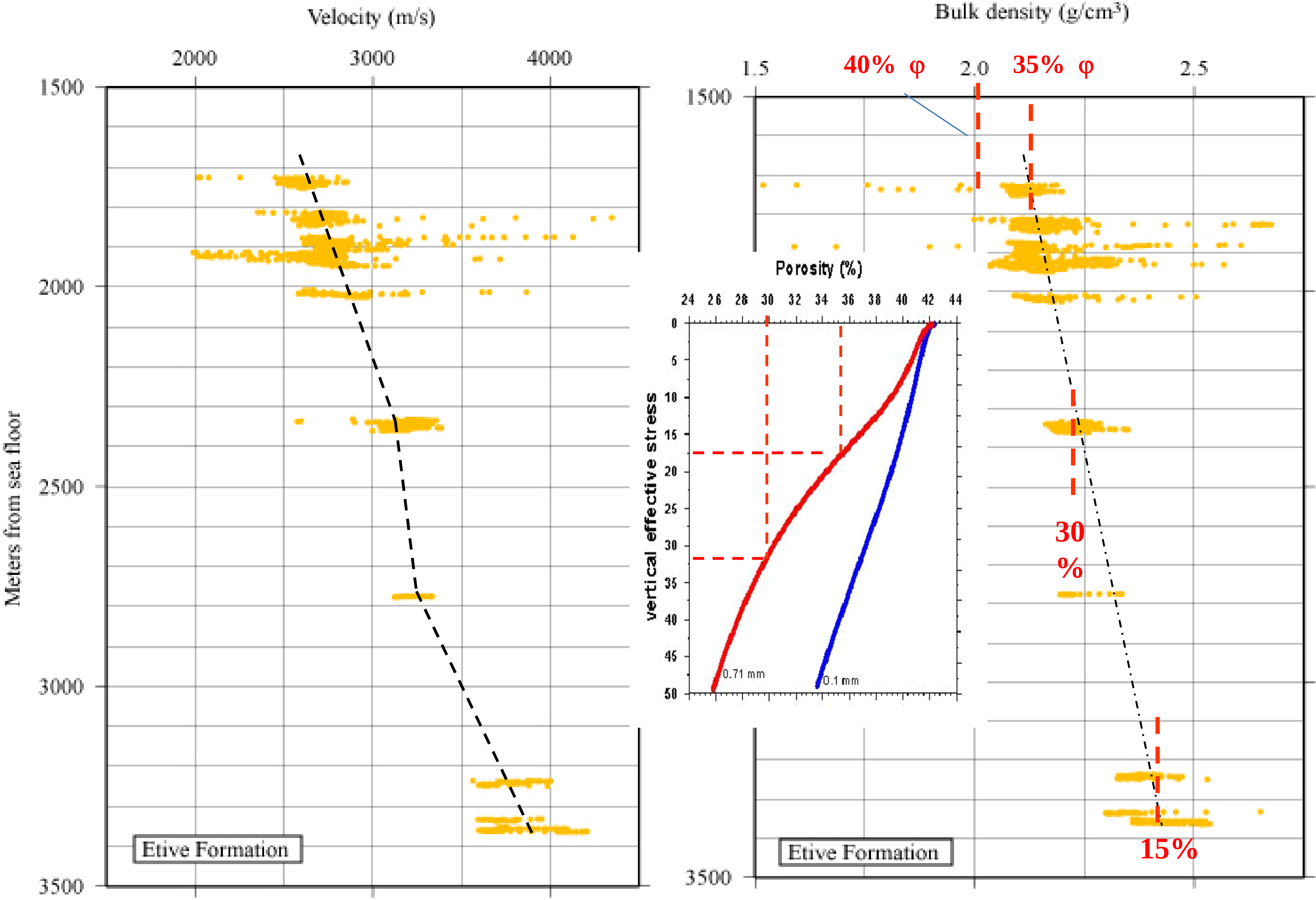
Sandstones – Etive Formation



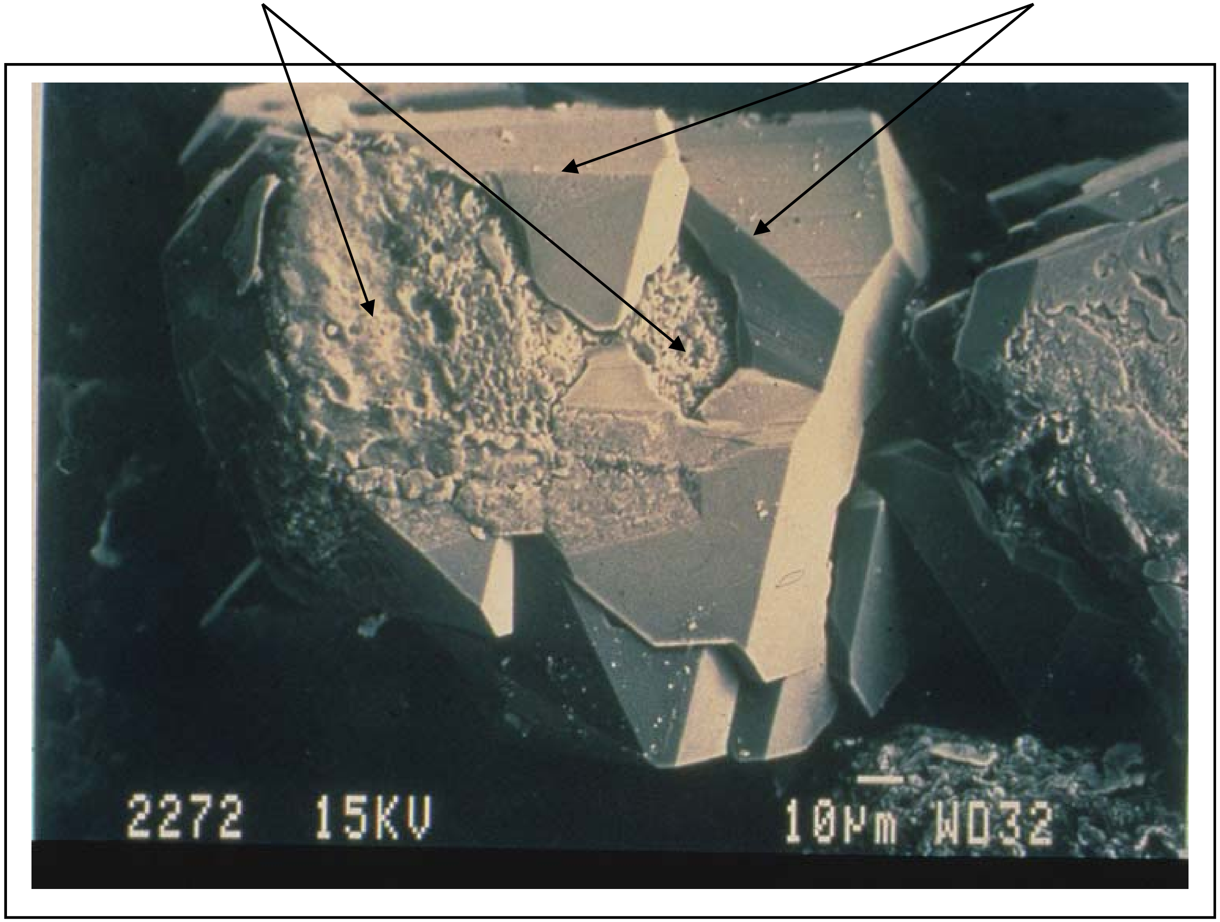


Marcussen et al., 2009, AAPG

Etive Fm velocity and density as a function of depth



Marcussen et al., 2009; AAPG

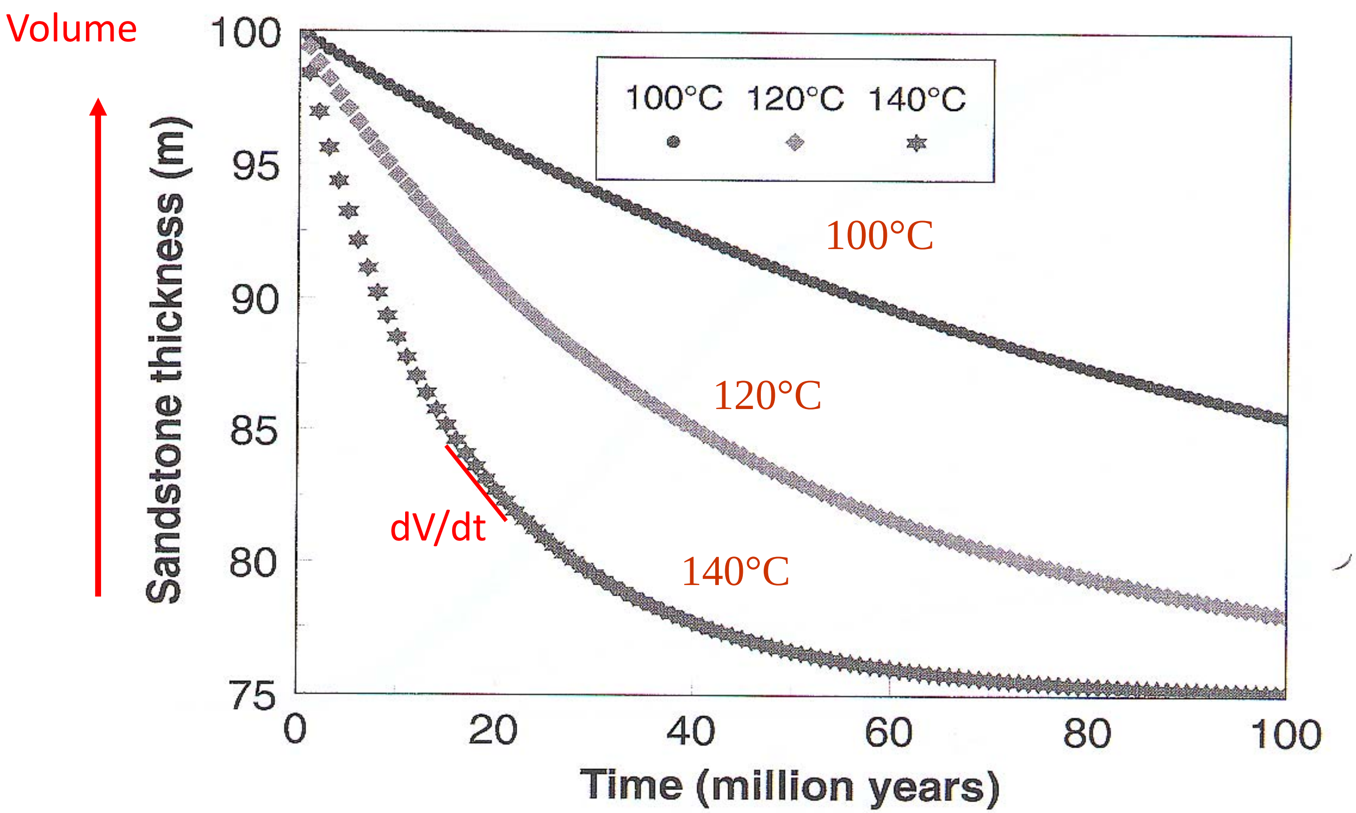


Primary clastic grain

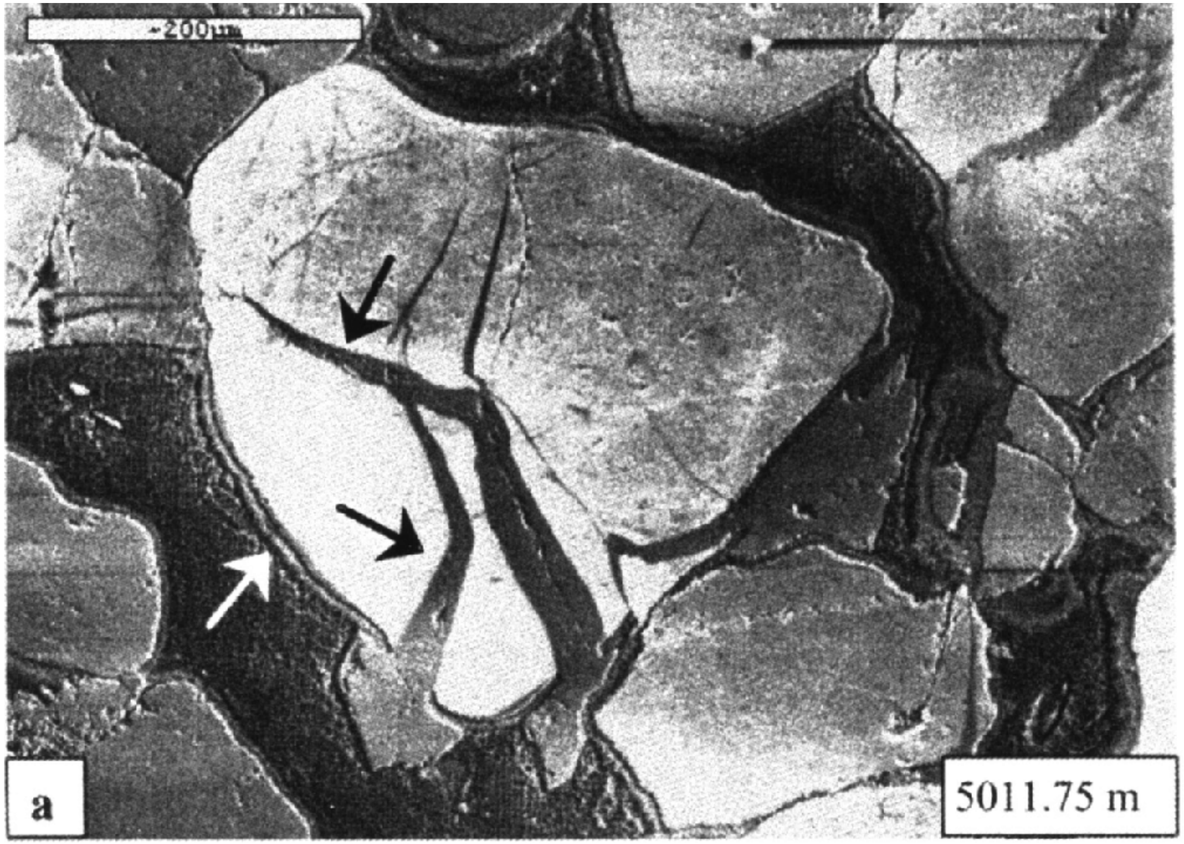
Quartz cement (overgrowth)

Quartz cement with smooth crystal surfaces as overgrowth on clastic grains

Compaction due to quartz cementation at constant temperature

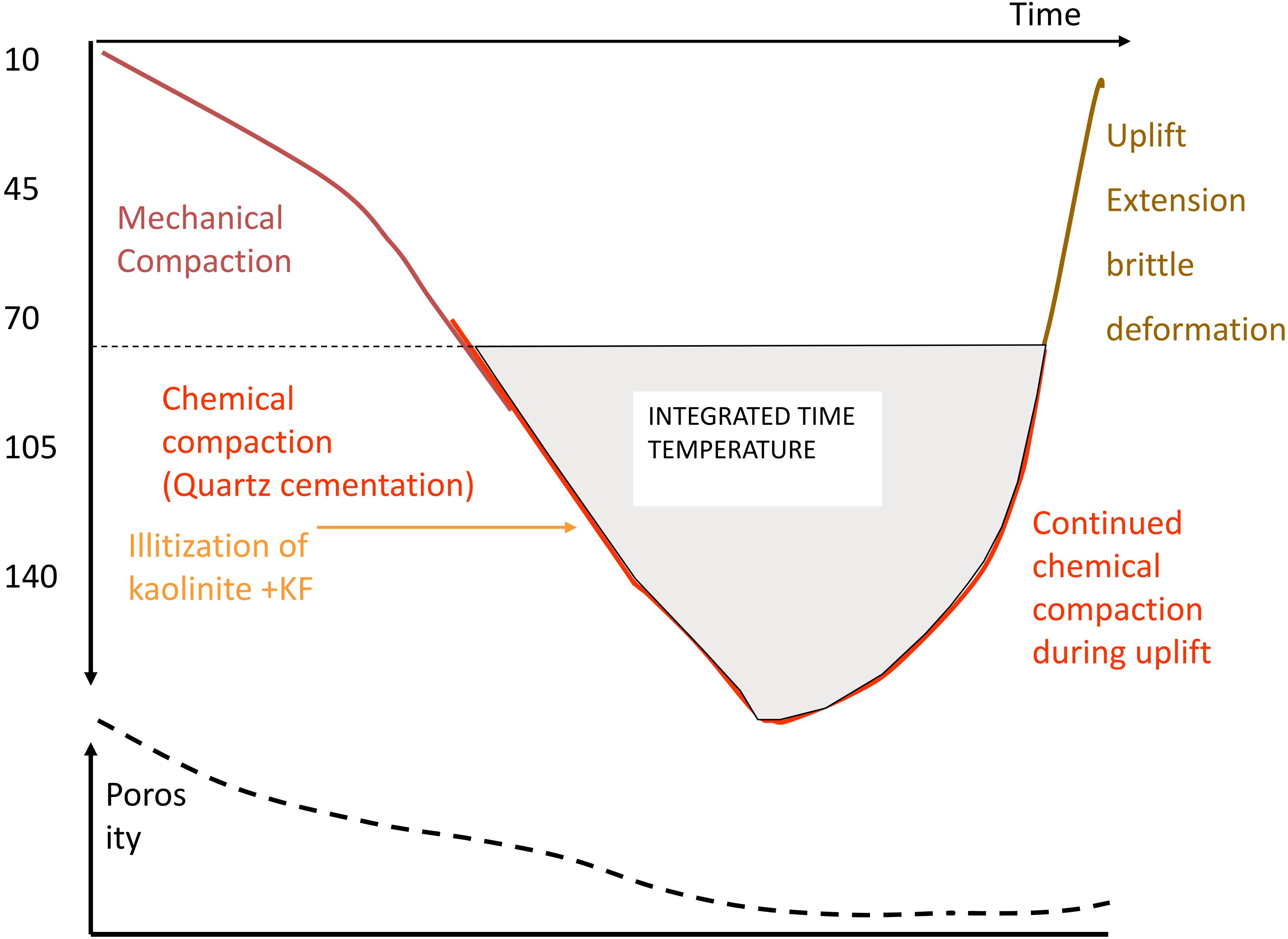


Walderhaug et. al 2001



Natural fractures in reservoir sandstone (Tilje Fm, Smørbukk Field). The quartz grains are chlorite coated but quartz cement have grown from fractured quartz From Chuhan et al. 2002

Diagenetic processes during burial.



Mechanical Compaction

Chemical compaction (Quartz cementation)

Illitization of kaolinite +KF

INTEGRATED TIME TEMPERATURE

Uplift

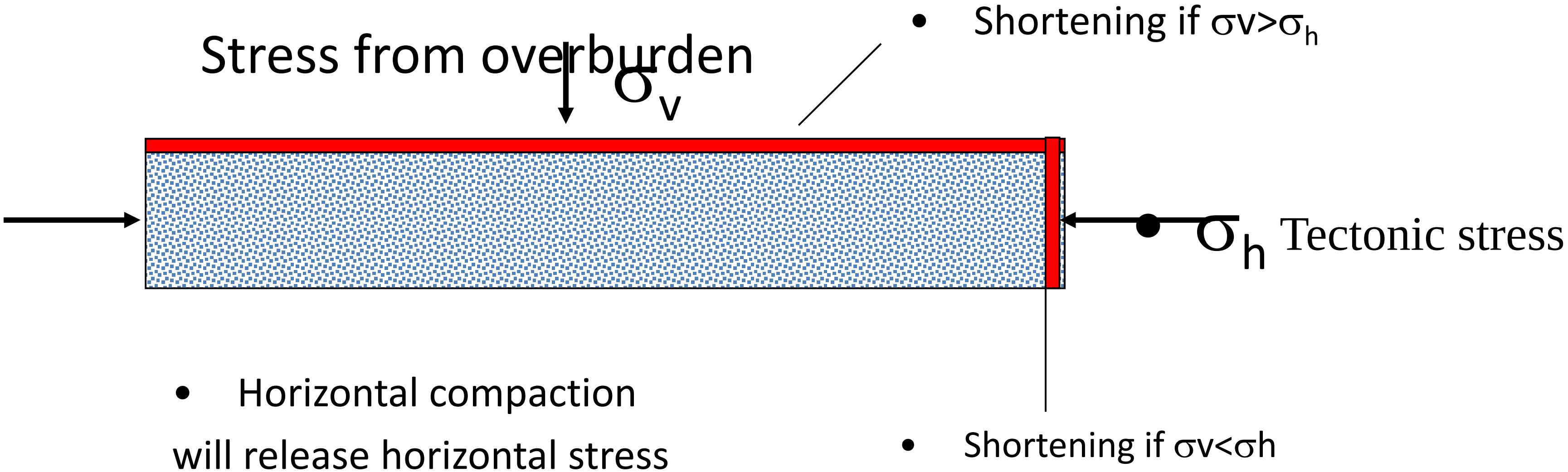
Extension

brittle

deformation

Continued chemical compaction during uplift

Vertical or horizontal compaction



- Shortening if $\sigma v > \sigma_h$

Stress from overburden σ_v

σ_h Tectonic stress

- Horizontal compaction

will release horizontal stress

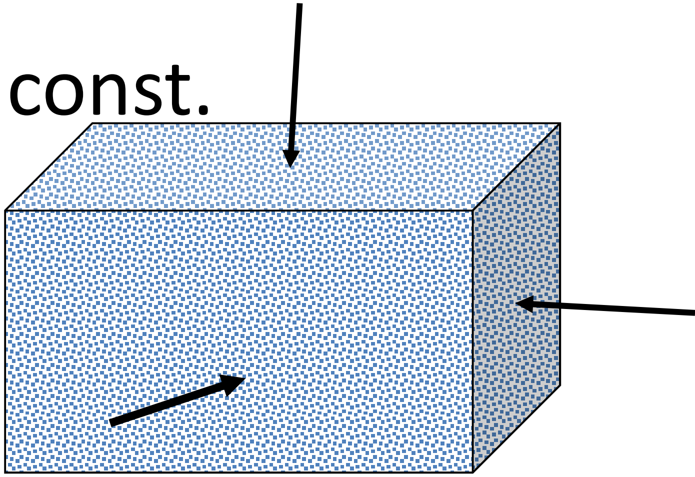
Equal to the elastic strain

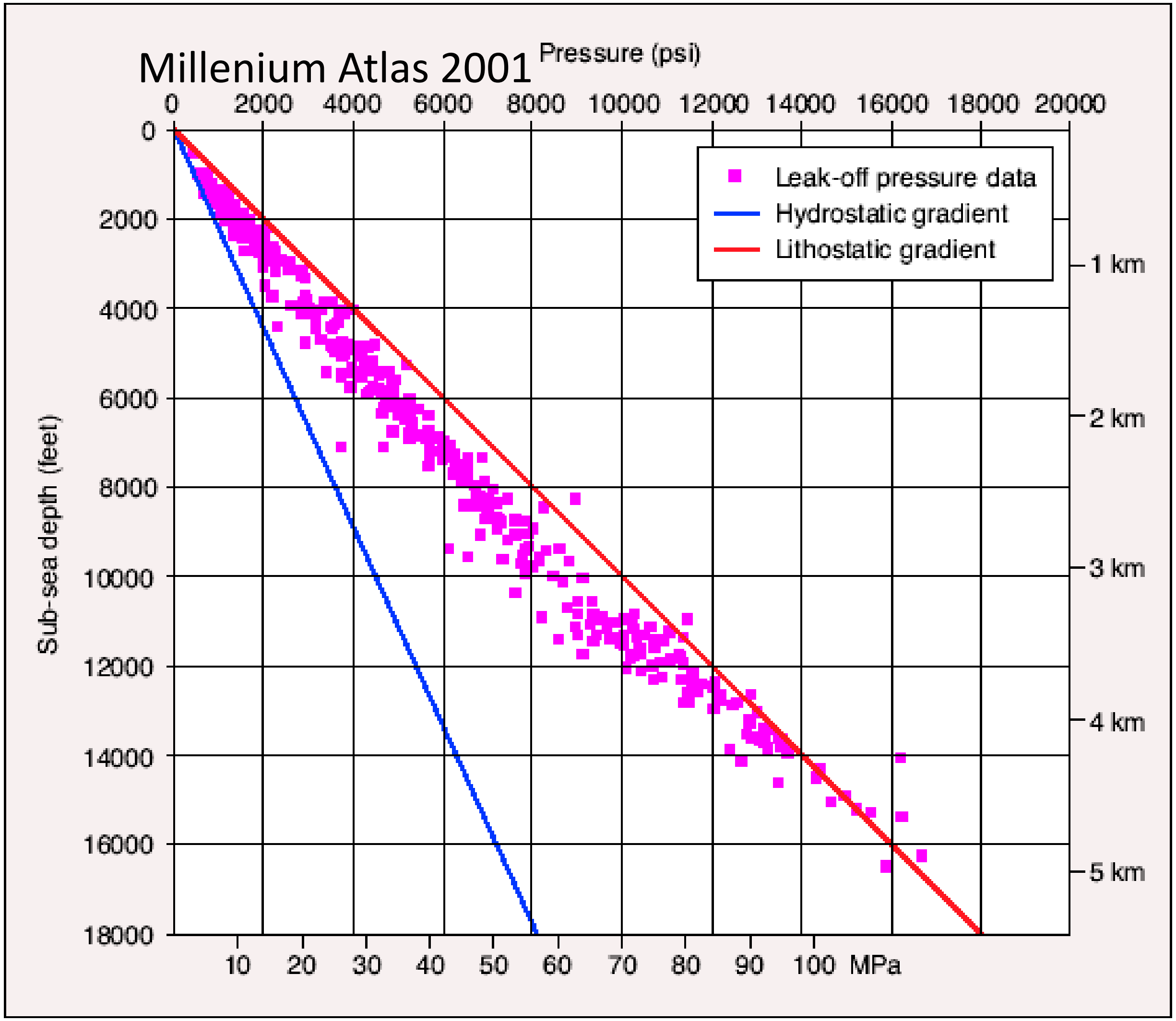
- Shortening if $\sigma v < \sigma h$

- If the basement is shortened the overlying sediments will compact horizontally and the horizontal strain will reduce the build up of horizontal stress

Sediment compaction – rock shrinkage

- Bulk modulus = Stress/strain(ΔV)
- If the strain ΔV is 0.001 or 0.1 % and the Bulk modulus is 50G Pa the effective stress is reduced by 50 MPa
- k volume (V_R)= Solids (V_S)+ Fluids (porosity
- Void Ratio = $V_S/V_f = \varphi/(1-\varphi)$
- For isochemical reactions V_S = const.
- $\Delta V = \Delta\varphi$, $dV/dt = d\varphi/dt$




Millenium Atlas 2001

Leak off pressures suggest that the horizontal stress is close to the vertical overburden stress

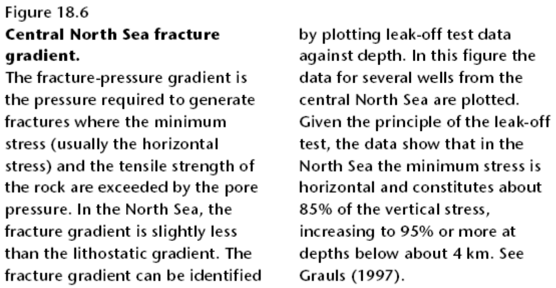
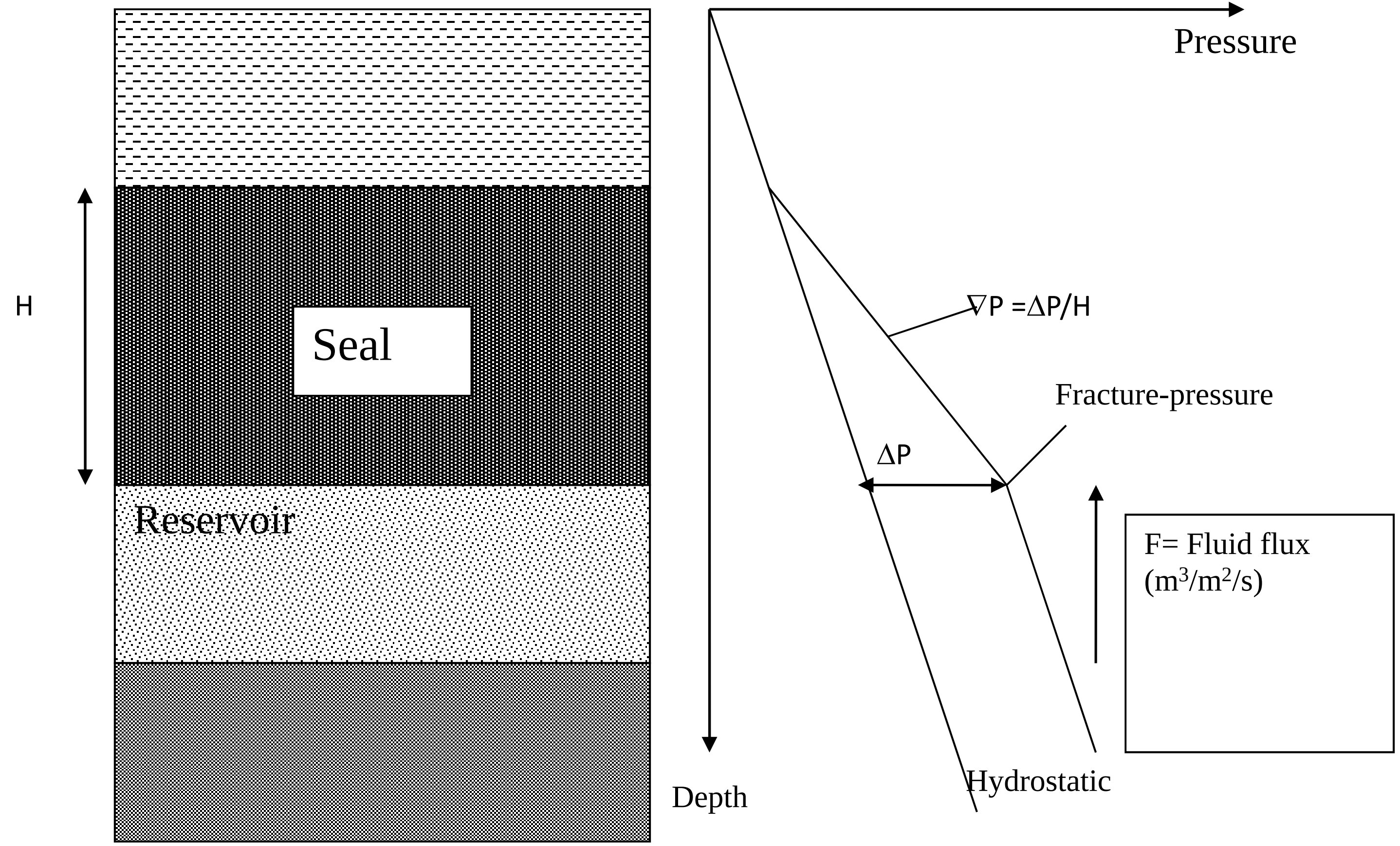


Figure 18.6
Central North Sea fracture gradient.
The fracture-pressure gradient is the pressure required to generate fractures where the minimum stress (usually the horizontal stress) and the tensile strength of the rock are exceeded by the pore pressure. In the North Sea, the fracture gradient is slightly less than the lithostatic gradient. The fracture gradient can be identified by plotting leak-off test data against depth. In this figure the data for several wells from the central North Sea are plotted. Given the principle of the leak-off test, the data show that in the North Sea the minimum stress is horizontal and constitutes about 85% of the vertical stress, increasing to 95% or more at depths below about 4 km. See Grauls (1997).

At great depth the compaction driven fluid flux is very low but the permeabilities of shales are close to zero



$$F = \left(\int_{z_1}^{z_2} \frac{\partial \phi}{\partial z} dz\right) \cdot \frac{\partial z}{\partial t}$$

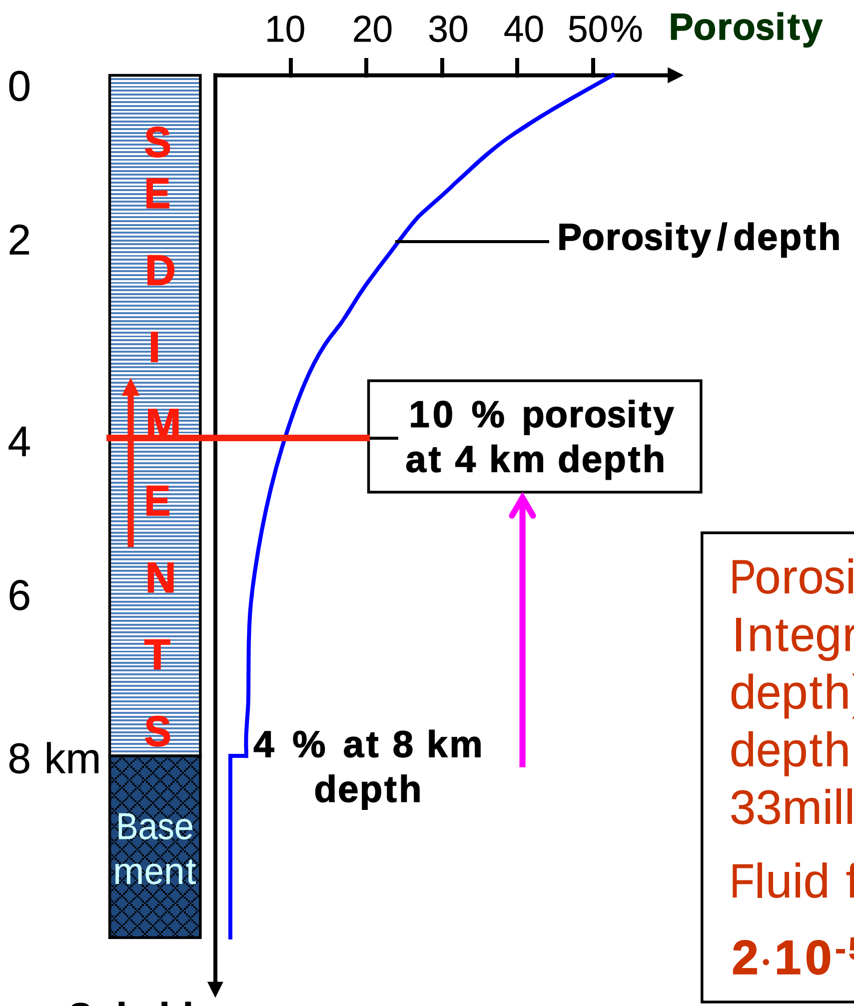
Sedimentation rate 2.10-5 m/yr

Flux=1.5 10^{-13} $m^3/m^2 s$

Permeability(k)= 0.01 nD

$F = k \cdot \nabla P/\mu$ At greater depth the compaction driven flux is a function of temperature rather than effective stress At constant viscosity k and $\cdot\nabla P$ vary inversely.

Compaction driven fluid fluxes in the deeper parts of sedimentary basins



Subsidence

3.10^{-5} m/yr

$F = k \cdot \nabla P/\mu$

The compaction driven flux is relatively constant over time

Porosity loss/km subsidence 1.5% Integrated flux (from 4-8km depth) pr km subsidence at 4 km depth: Total flow 60m^3/m^2 over 33mill years.

Fluid flux=60 m^3/m^2./$33 \cdot 10^6$yr=

$2 \cdot 10^{-5} m^3/m^2yr$.

Compaction

- Elastic Stress/strain compared with mechanical ductile strain and chemical strain.

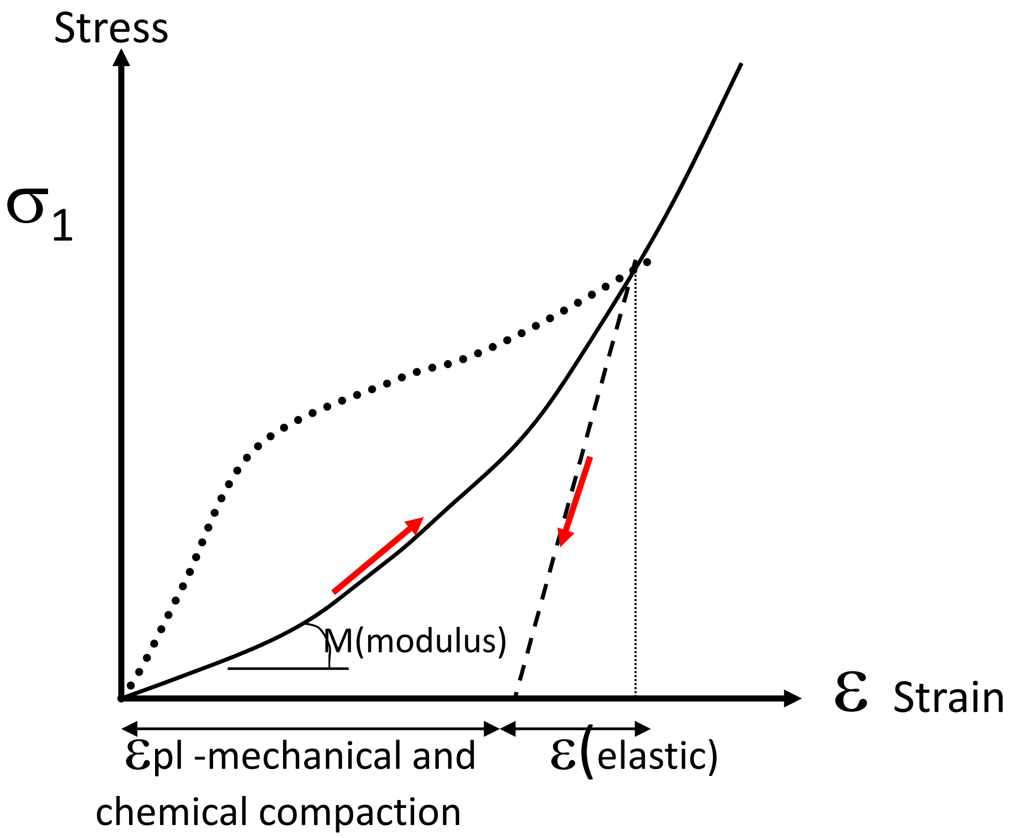
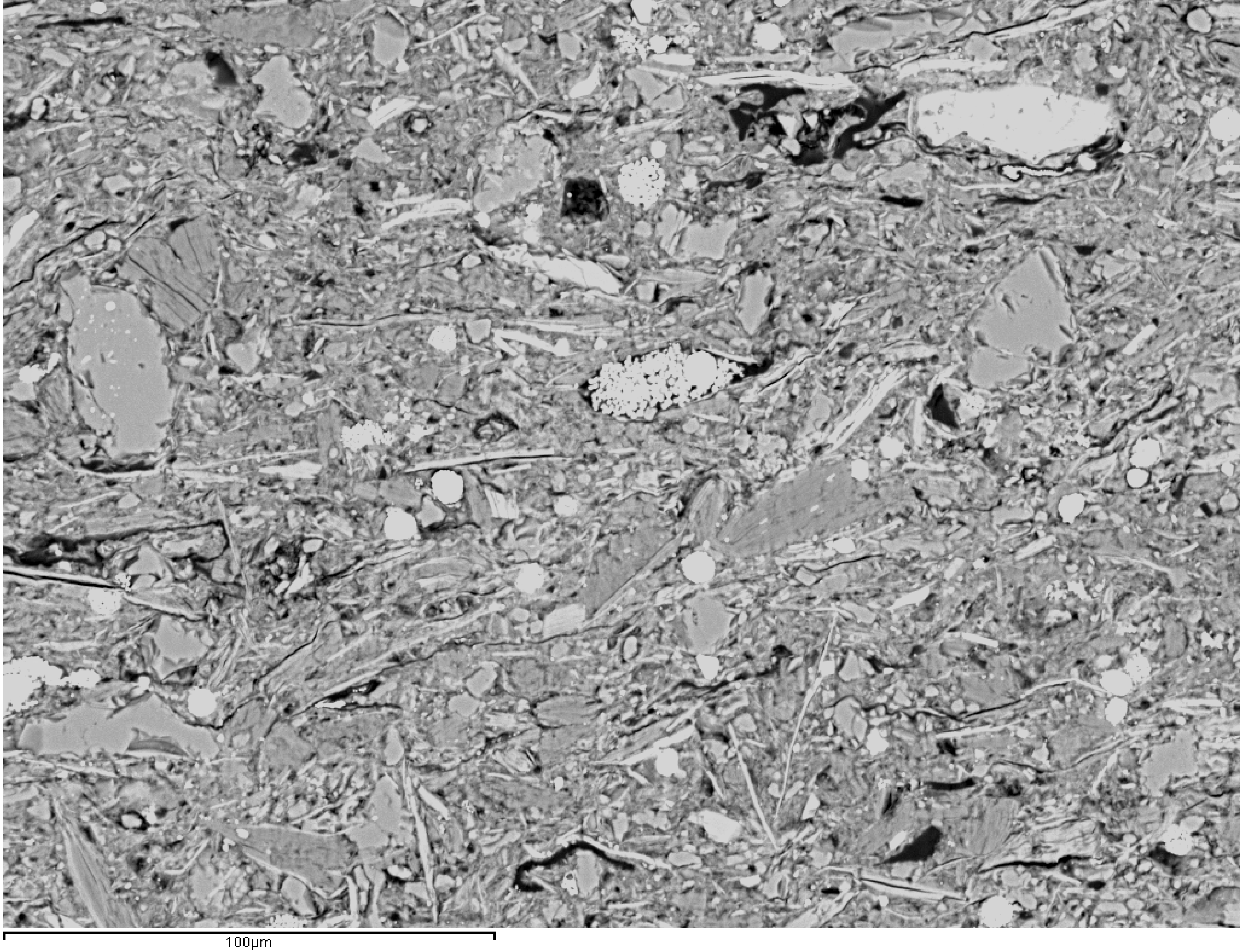
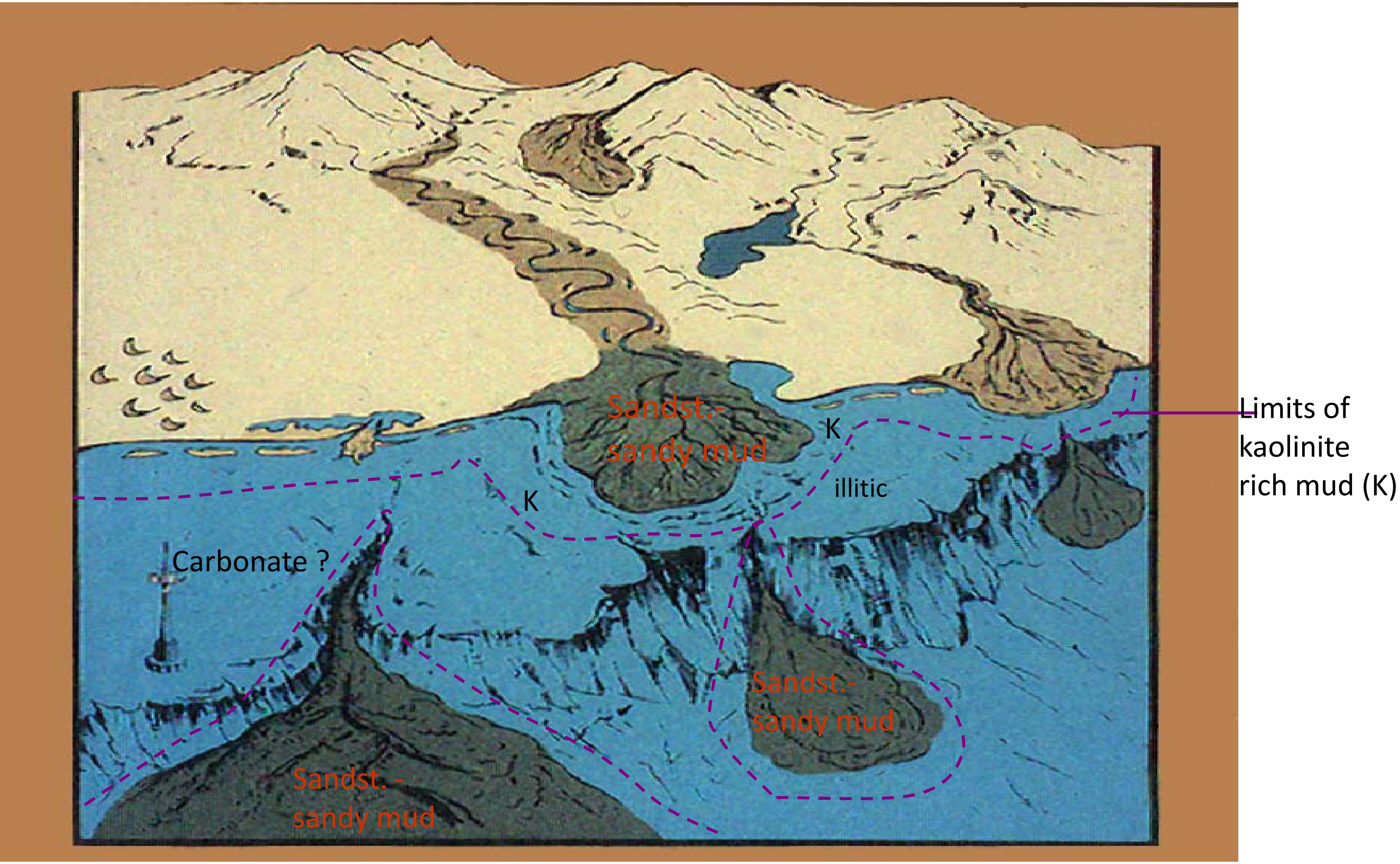


Fig11 K. B



6506/11-7 4479,33m Lange

E_{50}=13,77GPa μ_{50}=0,53 Vp=4118m/s Vs=2001m/s



The properties of sedimentary rocks are a function of provenance, depositional environment and diagenesis.

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Conclusions

The physical properties of sedimentary rocks change continuously during progressive burial and also during uplift and unloading.

Prediction of the distribution of rock properties must be based on the primary sediment composition and the burial histories.

Experimental compaction of sand and clay helps to predict the physical propertiesof sandstones and mudstones at moderate depths.
Experimental compaction of carbonates may simulate both mechanical and chemical compaction.
Compaction processes are also important for the permeability reduction in shales(cap rocks) and quartz cementation here plays an important role.

The inversion from geophysical data, (including EM data) to rock properties and fluid saturation requires a better data base for rock properties as a function of mineralogy and textural relationships.