Dilation factor as function of geological time

Kenneth Duffaut
Associate Professor

Faculty of Engineering Science and Technology
Department of Petroleum Engineering
and Applied Geophysics
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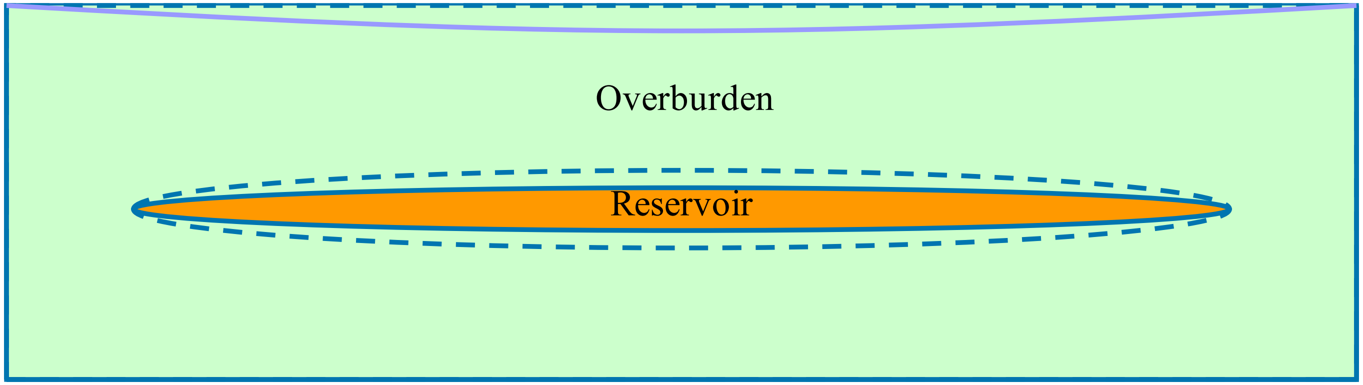
Introduction
4D or time-lapse traveltime analysis



$$\frac{\Delta t_0(x_0)}{t_0(x_0)} \approx \frac{\Delta z(x_0)}{z(x_0)} - \frac{\Delta v_{p0}(x_0)}{v_{p0}(x_0)}$$

(Landrø and Stammeijer, 2004)

$$\frac{\Delta v_{p0}(x_0)}{v_{p0}(x_0)} = \alpha \frac{\Delta z(x_0)}{z(x_0)}$$

(Røste et al., 2005)

$$R = -\alpha$$

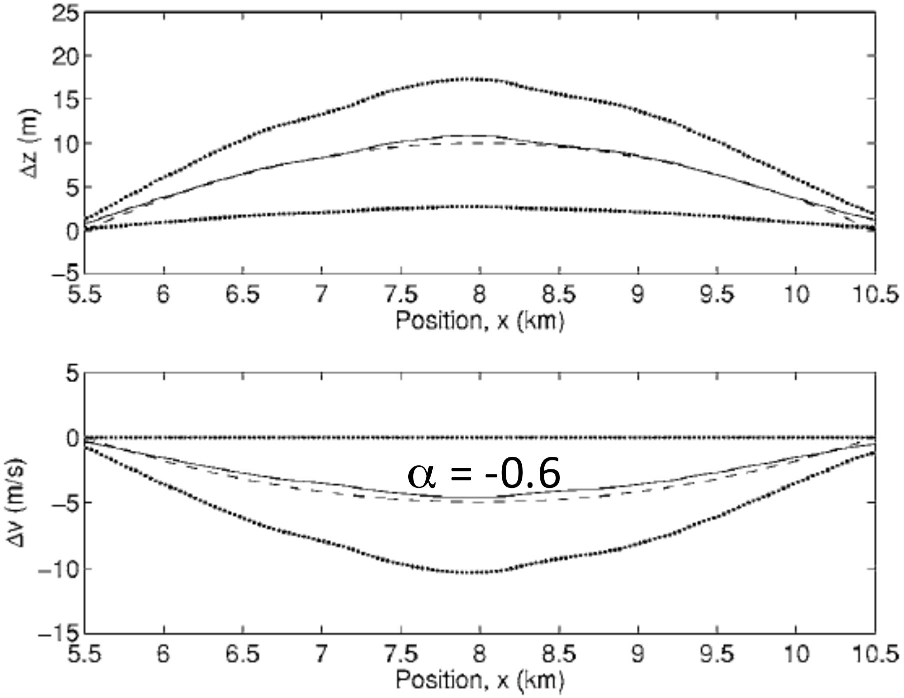
(Hatchell et al., 2005)

Relative thickness change and velocity change

$$\frac{\Delta z(x_0)}{z(x_0)} = \frac{1}{(1-\alpha)} \frac{\Delta t_0(x_0)}{t_0(x_0)}$$

$$\frac{\Delta v_{p0}(x_0)}{v_{p0}(x_0)} = \frac{\alpha}{(1-\alpha)} \frac{\Delta t_0(x_0)}{t_0(x_0)}$$

Optimal α = -0.6 for all lateral positions

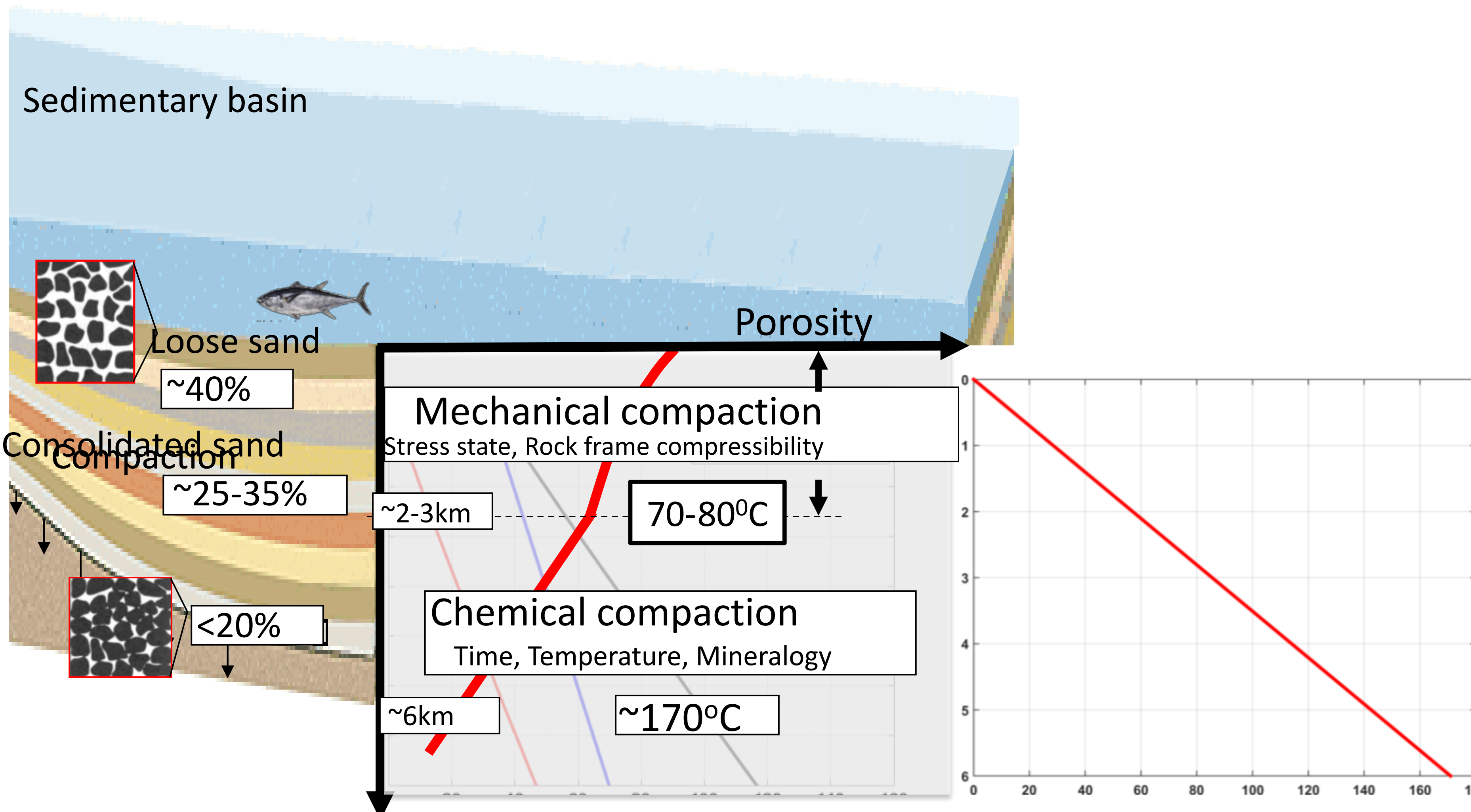


(Figure courtesy: Røste et al., 2006)

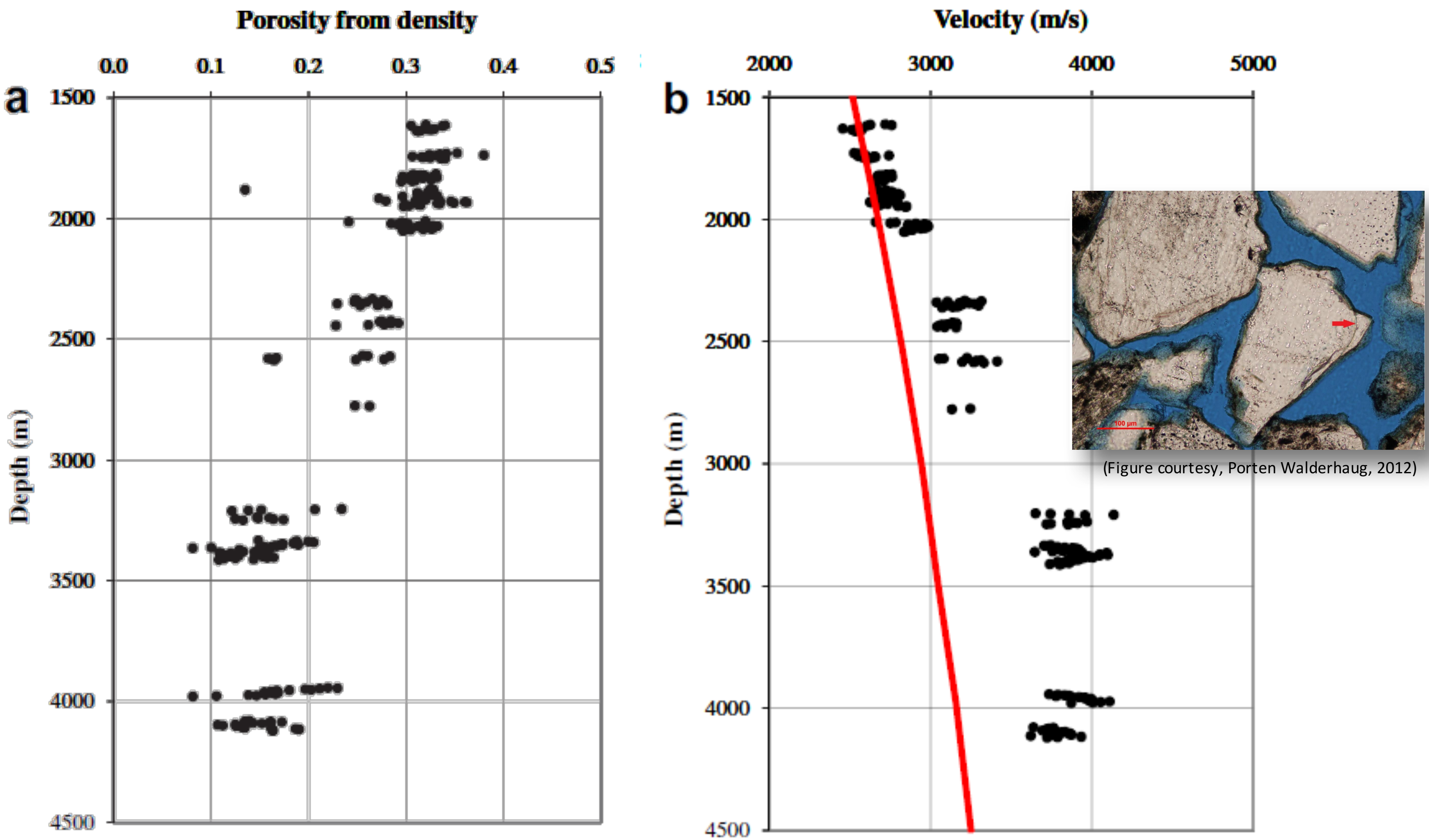
Outline

- Introduction
- The model
- Modelling results
- Conclusions

Sediment Compaction



Porosity-Velocity depth trends – North Sea



(Figure courtesy, Marcussen et al., 2010)

(Figure courtesy, Porten Walderhaug, 2012)

The model

Vertical thinning due to quartz cementation in sandstones

Volume of precipitated quartz (Walderhaug, 1996)

$$\frac{dV_q}{dt} = \frac{MrA}{\rho}$$

Total volume change

$$dV = dV_q + dV\frac{V_\varphi}{V}$$

Rearrange and combine

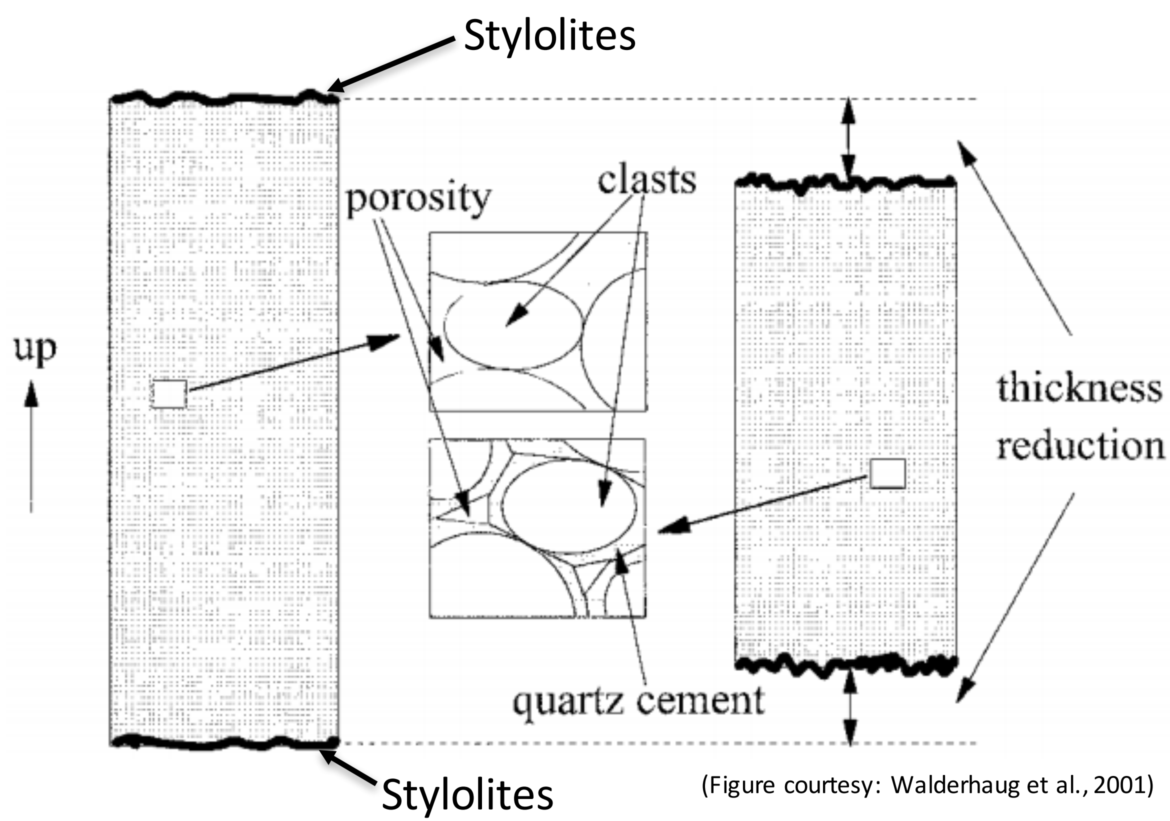
$$\frac{dV}{dt} = -\frac{MrAV}{\rho\left(V - V_\varphi\right)}$$

Surface area

$$A = A_0\frac{V_\varphi}{V_{\varphi_0}}$$

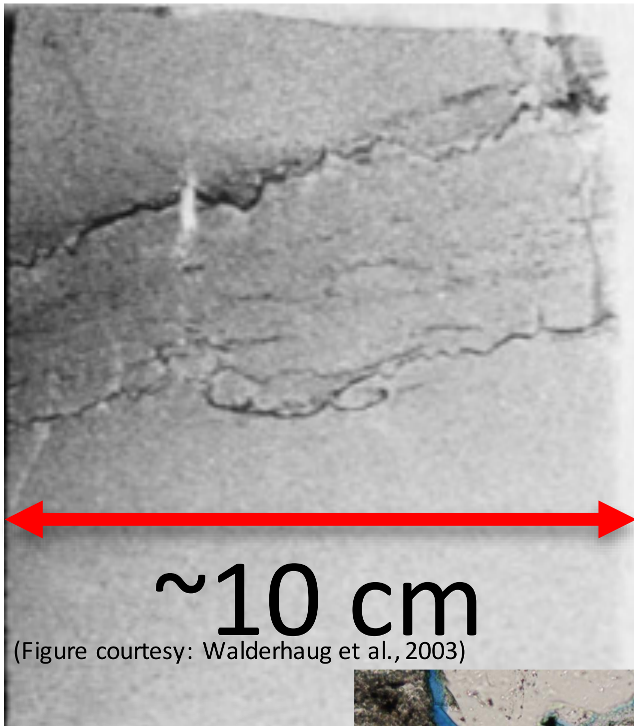
$$\frac{dV}{dt} = -\frac{MrA_0}{\rho V_{\varphi_0} V_s} V(V - V_s)$$

(Walderhaug et al., 2001)

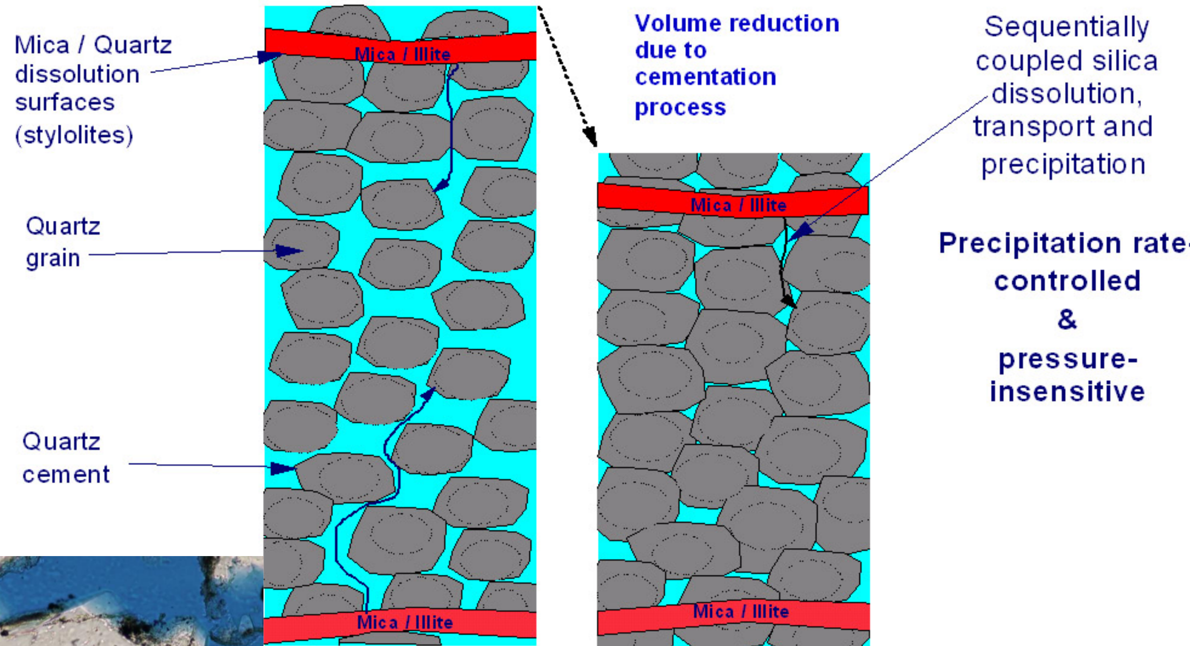


(Figure courtesy: Walderhaug et al., 2001)

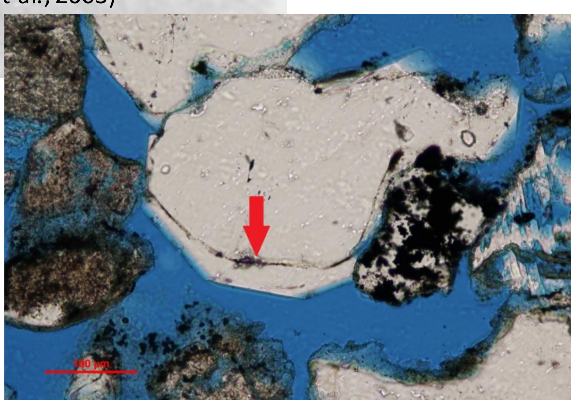
Examples of stylolites and quartz cement



(Figure courtesy: Walderhaug et al., 2003)



(Figure courtesy: Bjørkum, 2008)


(Figure courtesy: Porten Walderhaug, 2012)

Model assumptions

- Local redistribution, no import or export of silica
- Horizontal stylolites – volume reduction is a vertical thinning
- No mechanical compaction takes place
- No other diagenetic precipitation or dissolution reactions are active

Volume change at constant temperature

$$\frac{dV}{dt} = -\frac{MrA_0}{\rho V_{\varphi_0} V_s} V(V - V_s)$$

Quartz precipitation rate

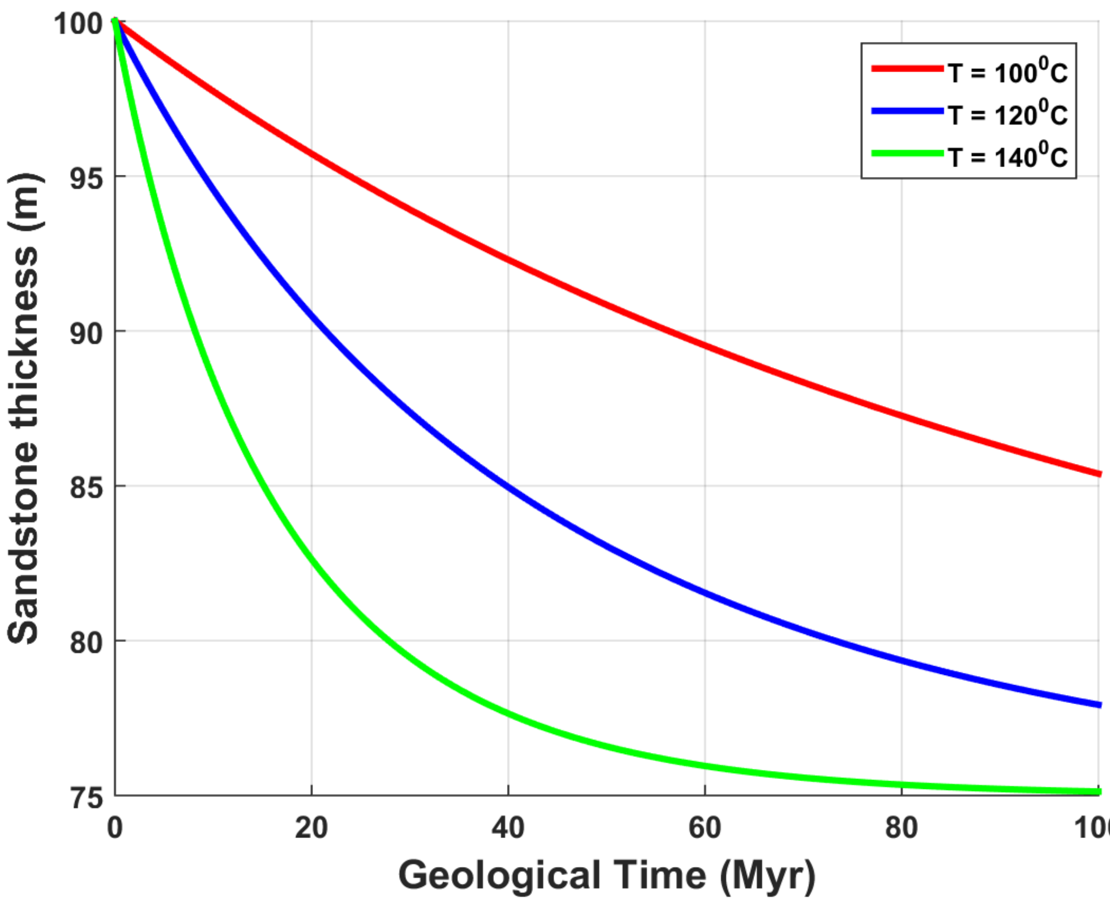
$$r \approx a10^{bT}$$

$$\int_{V_0}^{V} \frac{1}{v(v - V_s)} dv = -\frac{MrA_0}{\rho V_{\varphi_0} V_s} \int_{t_0=0}^{t} d\tau$$

$$V = \frac{V_0 V_s e^{\left(\frac{MrA_0 t}{\rho V_{\varphi_0}}\right)}}{\left(V_0 e^{\left(\frac{MrA_0 t}{\rho V_{\varphi_0}}\right)} - V_{\varphi_0}\right)}$$

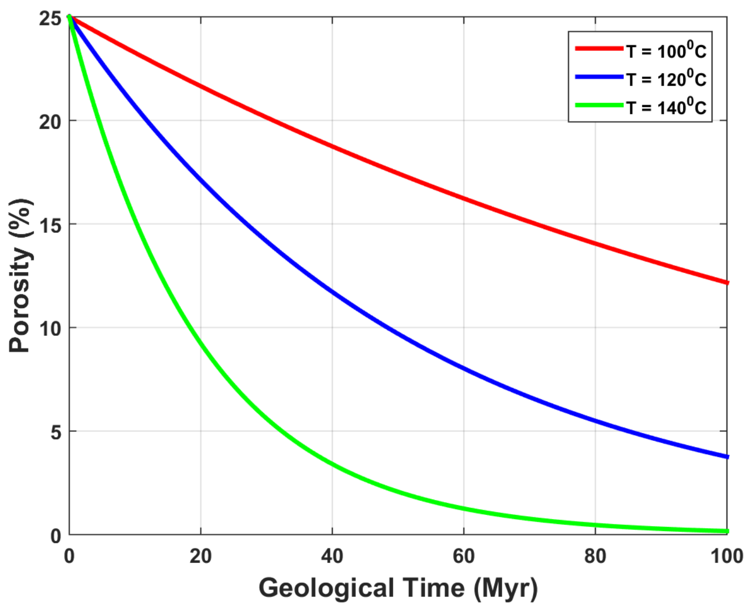
(Walderhaug et al., 2001)

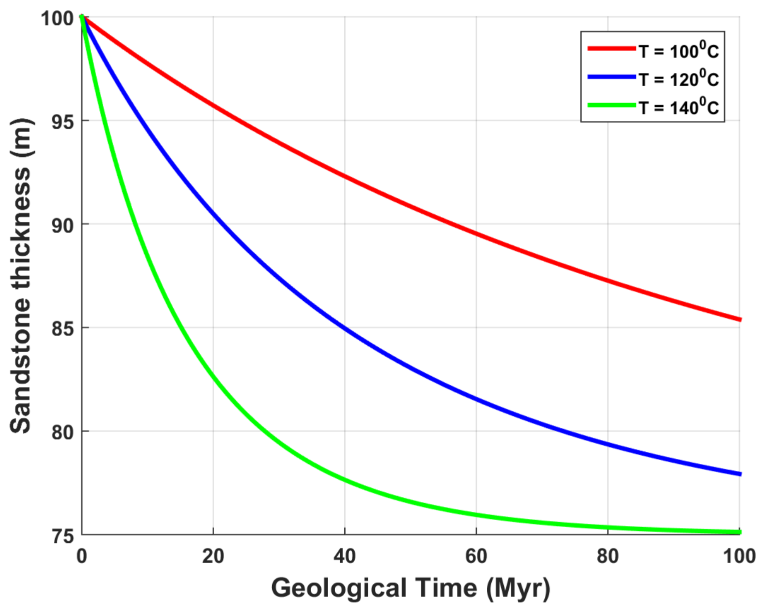
100 meter thick sandstone layer with 25% porosity @ t=0



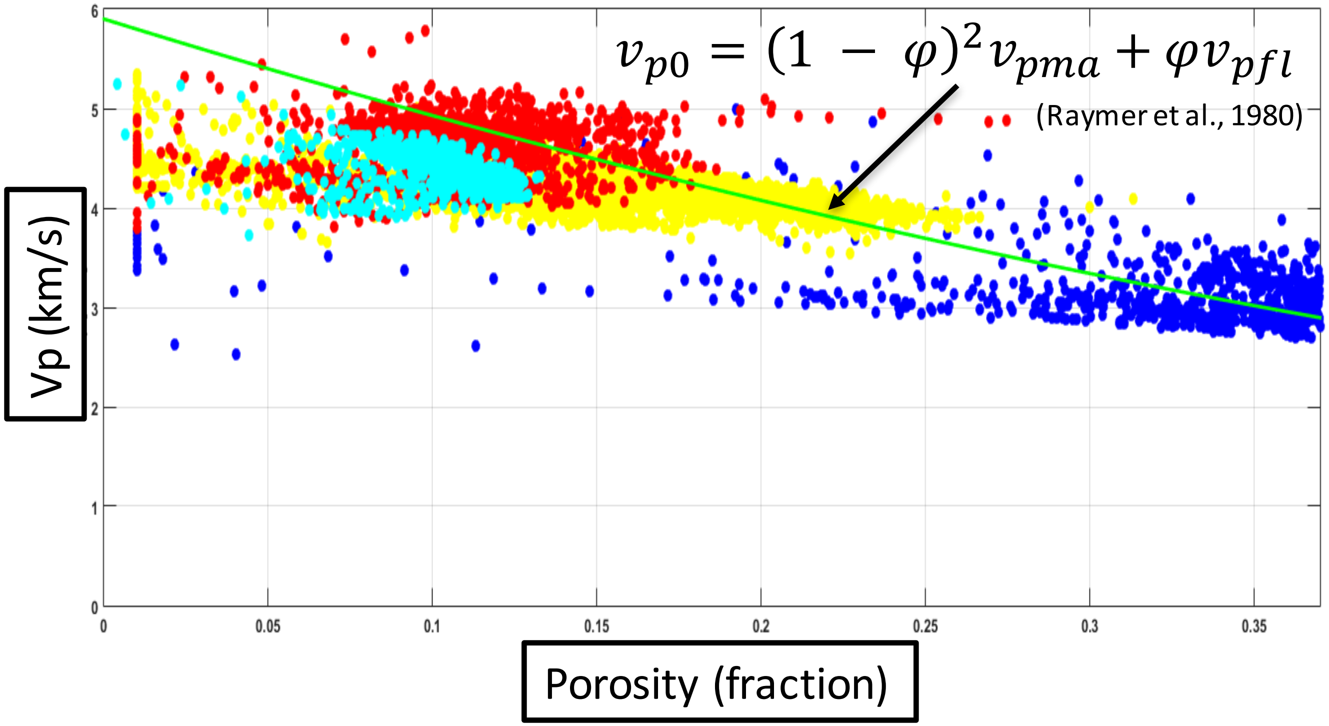
Porosity-volume change
Constant temperature

100 meter thick sandstone layer with 25% porosity @ t=0



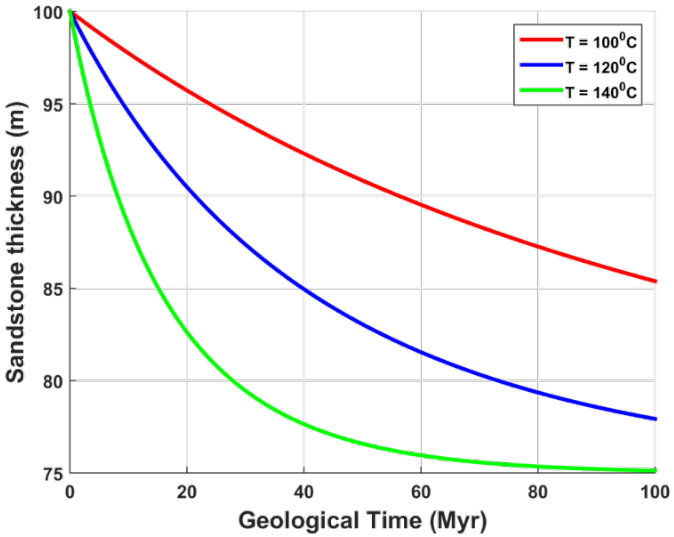


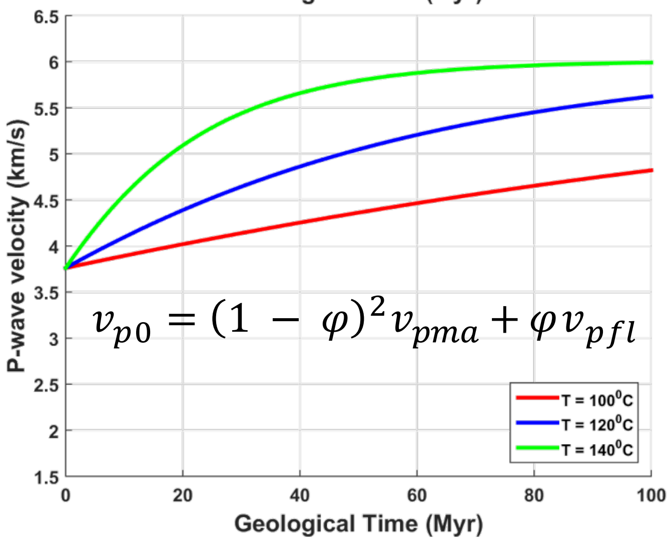
Velocity-porosity model
Consolidated sandstones from NCS



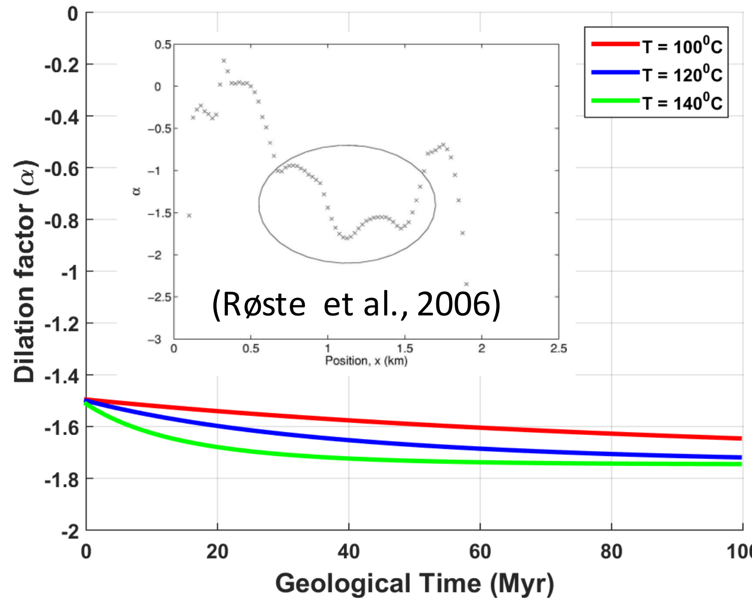
Dilation factor (α) as function of time
Constant temperature

$$\alpha = \frac{\Delta v_{p0}(x_0,t)}{v_{p0}(x_0,t)}\left(\frac{\Delta z(x_0,t)}{z(x_0,t)}\right)^{-1}$$





$$v_{p0} = (1-\varphi)^2 v_{pma} + \varphi v_{pfl}$$



Volume change during a linear temperature change a.f.o. time

$$\frac{dV}{dt} = -\frac{Mr A_0}{\rho V_{\varphi_0} V_s} V(V - V_s)$$

Quartz precipitation rate

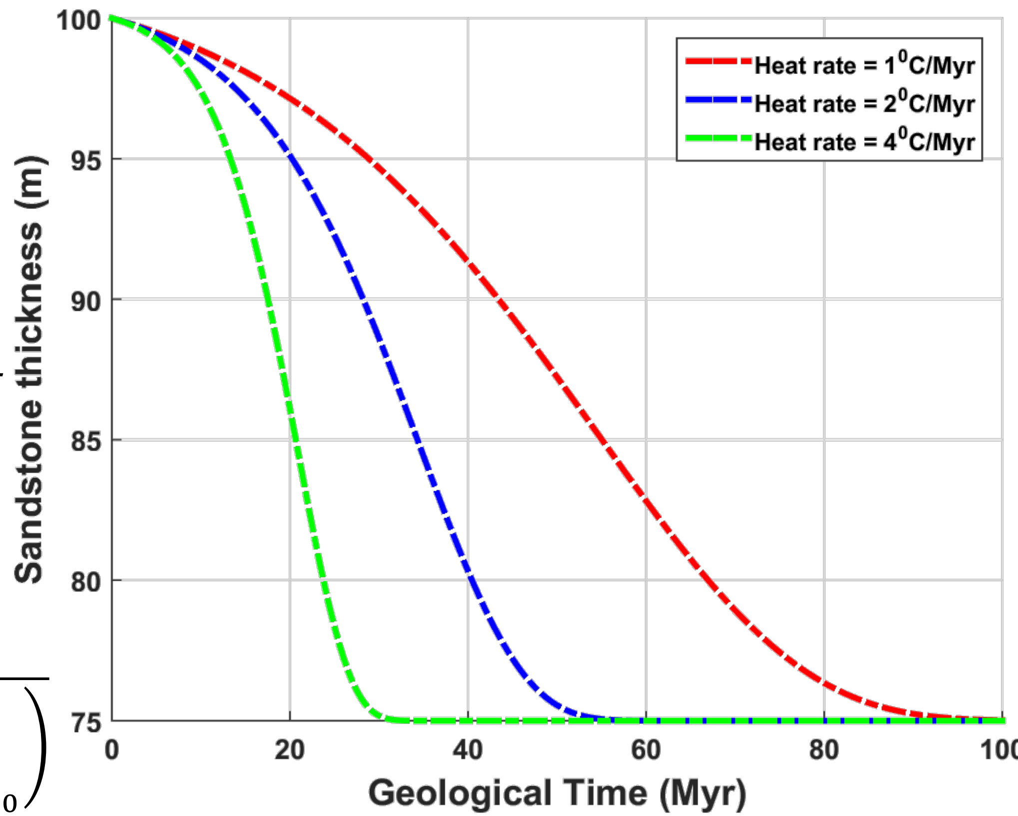
$$r \approx a10^{b(ct+d)}$$

$$\int_{V_0}^{V} \frac{1}{v(v - V_s)} dv = -\frac{M A_0 a}{\rho V_{\varphi_0} V_s} \int_{t_0=0}^{t} 10^{b(ct+d)} d\tau$$

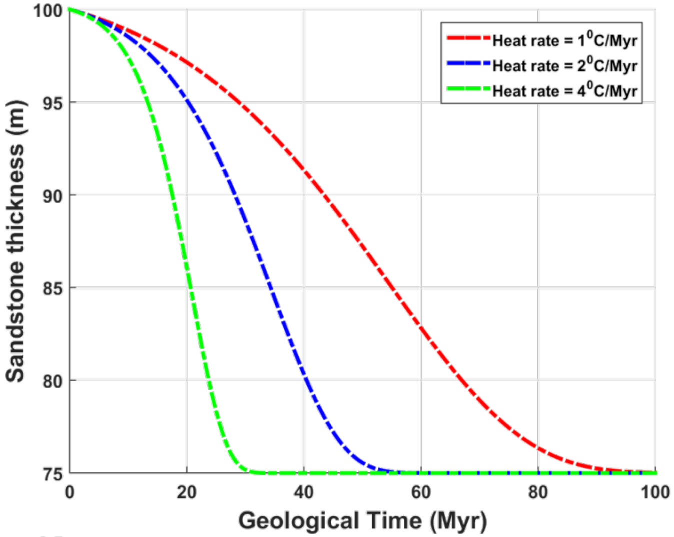
$$V = \frac{V_0 V_s e^{\left(\frac{M A_0 a}{\rho V_{\varphi_0} bc\ln(10)}\left(10^{b(ct+d)} - 10^{bd}\right)\right)}}{\left(V_0 e^{\left(\frac{M A_0 a}{\rho V_{\varphi_0} bc\ln(10)}\left(10^{b(ct+d)} - 10^{bd}\right)\right)} - V_{\varphi_0}\right)}$$

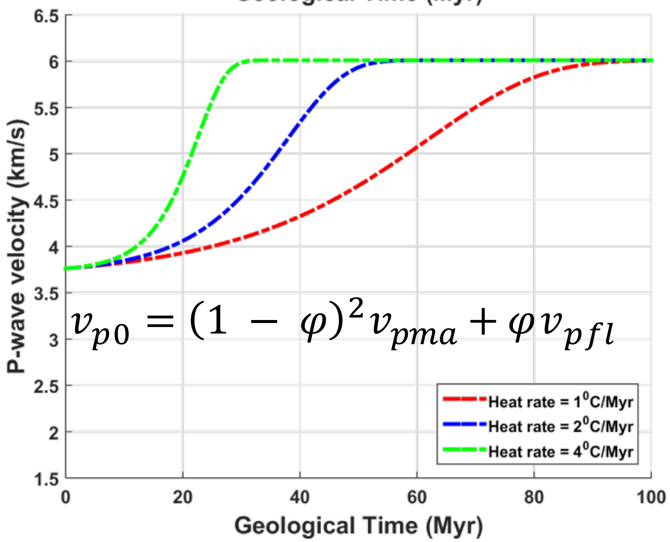
(Walderhaug et al., 2001)

100 meter thick sandstone layer with 25% porosity @ t=0



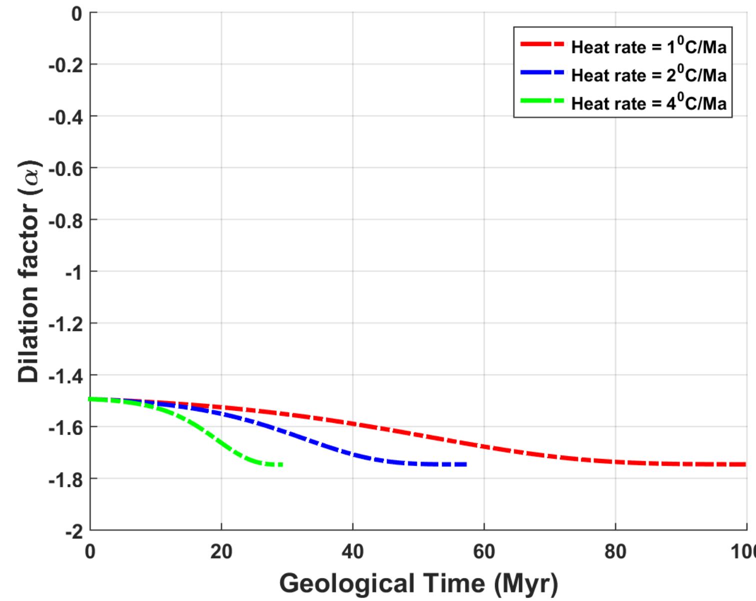
Dilation factor as function of time
Linear temperature change



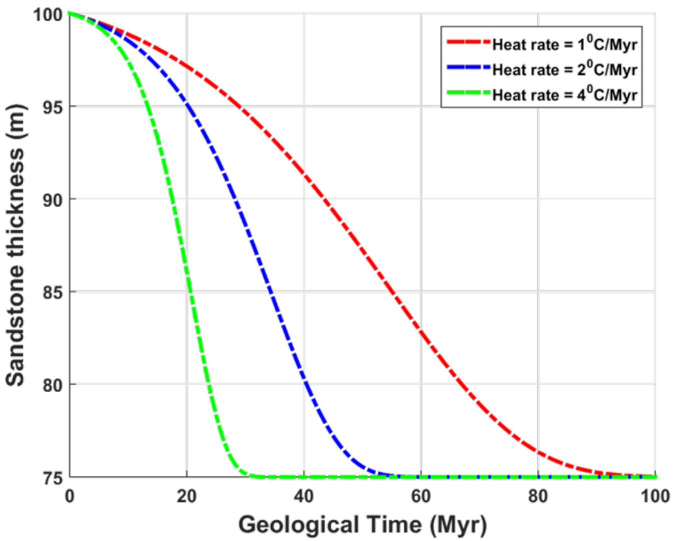


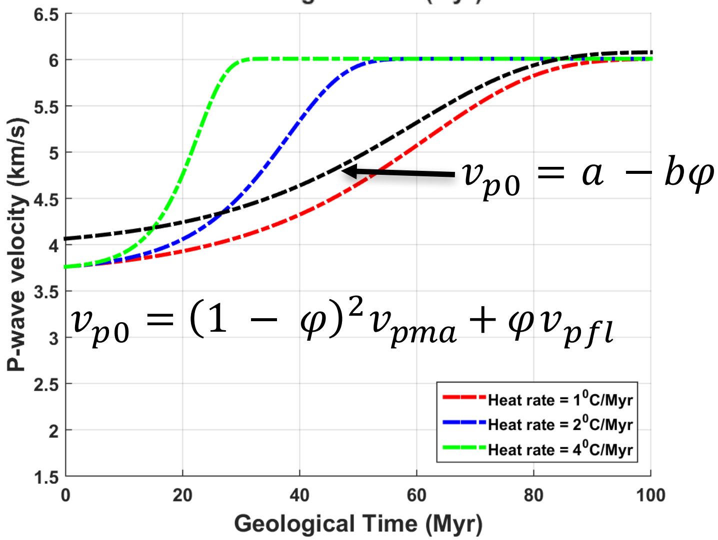
$$v_{p0} = (1 - \varphi)^2 v_{pma} + \varphi v_{pfl}$$

$$\alpha = \frac{\Delta v_{p0}(x_0, t)}{v_{p0}(x_0, t)} \left(\frac{\Delta z(x_0, t)}{z(x_0, t)} \right)^{-1}$$

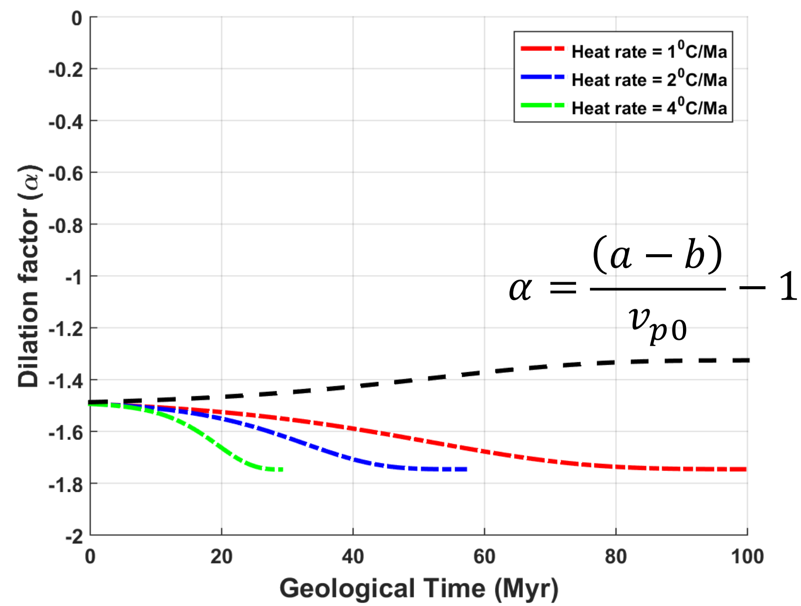


Dilation factor as function of time
Assuming a linear temperature change





$$\alpha = \frac{\Delta v_{p0}(x_0,t)}{v_{p0}(x_0,t)}\left(\frac{\Delta z(x_0,t)}{z(x_0,t)}\right)^{-1}$$

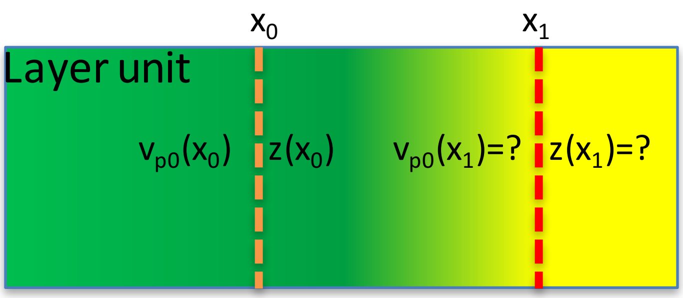


Conclusions

- The dilation factor (α) of the reservoir is described as function of the rate of vertical thinning of sandstones due to quartz cementation.
- Two cases are tested
  - Constant temperature
  - Linear temperature increase
- Given the model assumptions
  - The dilation factor range between -1.5 to -1.75

Spatial zero offset traveltime analysis RoSe presentation 2015

t_0 = two-way vertical time thickness of unit at x_0
x_0 = coordinate reference position along a line
x_1 = a new coordinate position along the line
z = thickness of formation unit
v_{p0} = vertical P-wave velocity of unit
Δ = spatial difference in physical parameters
α = Dilation factor



$$t_0(x_0) = \frac{2z(x_0)}{v_{p0}(x_0)}$$

$$\frac{\Delta t_0(x_1,x_0)}{t_0(x_0)} \approx \frac{\Delta z(x_1,x_0)}{z(x_0)} - \frac{\Delta v_{p0}(x_1,x_0)}{v_{p0}(x_0)}$$

$$\frac{\Delta v_{p0}(x_1,x_0)}{v_{p0}(x_0)} = \alpha(x_0)\frac{\Delta z(x_1,x_0)}{z(x_0)}$$

$$\frac{\Delta z(x_1,x_0)}{z(x_0)} = \frac{1}{(1-\alpha(x_0))}\frac{\Delta t_0(x_1,x_0)}{t_0(x_1,x_0)}$$

$$\frac{\Delta v_{p0}(x_1,x_0)}{v_{p0}(x_0)} = \frac{\alpha(x_0)}{(1-\alpha(x_0))}\frac{\Delta t_0(x_1,x_0)}{t_0(x_1,x_0)}$$

Acknowledgement

- RoSe for giving me the opportunity to present

Thank you for your attention