# Time dependent subsidence modeling

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# Natural Gas Production

- reduces the pore pressure $u$ in the rock formation of the reservoir (u↓)

$$\sigma = \sigma' + u$$

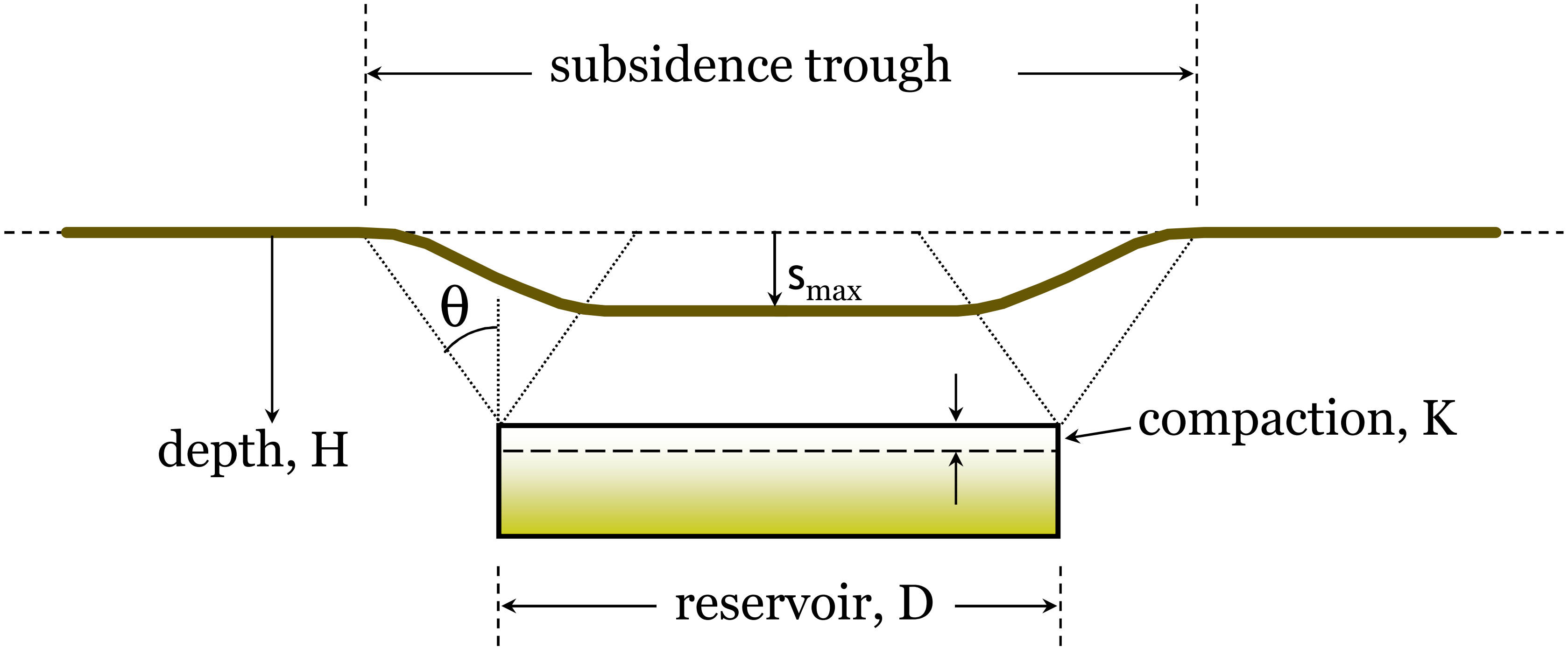
Terzaghi principle

- may cause the compaction of the reservoir if the effective stress $\sigma'$ increases ($\sigma'$↑, $\phi$↓)

# All reservoirs compact but it does not always lead to subsidence

it depends on the:

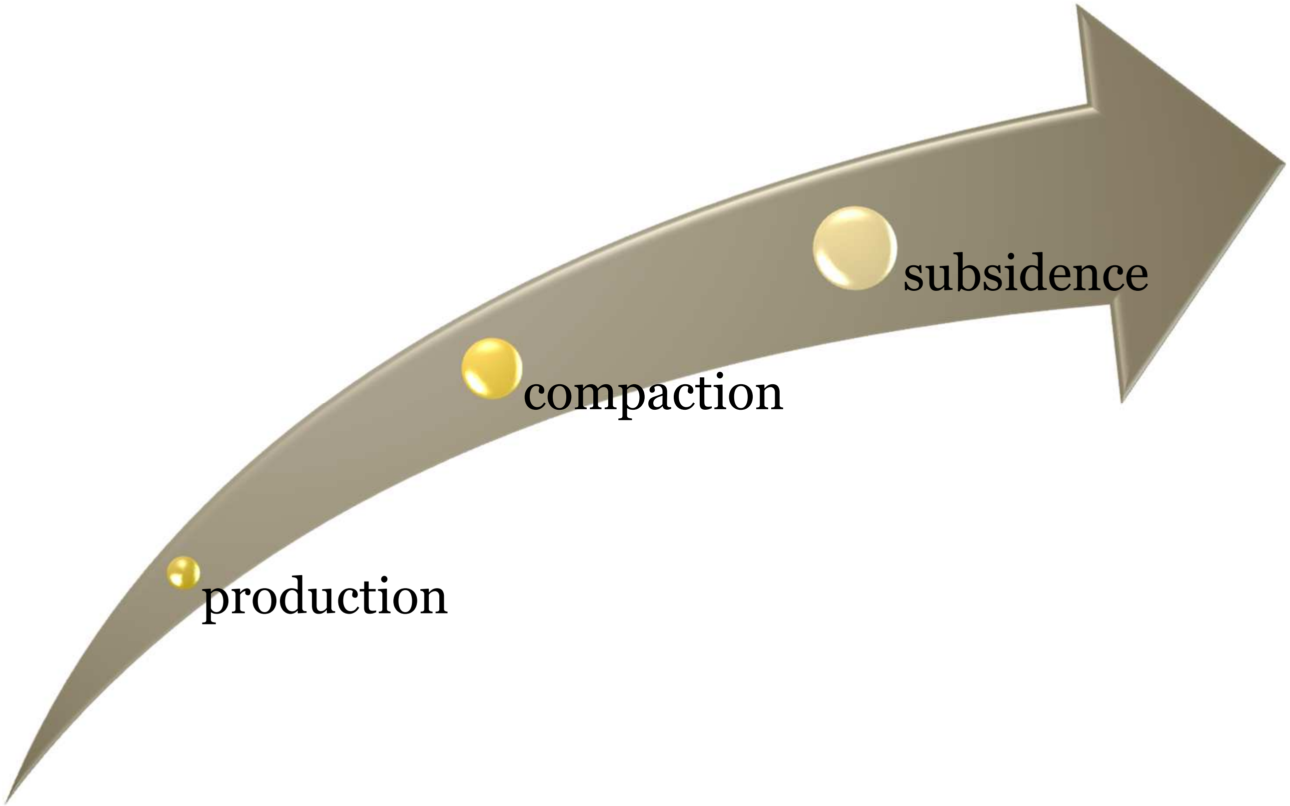
- dimension/depth ratio,
- total thickness of the reservoir,
- porosity of the reservoir



# Compaction

- may cause subsidence:
  - in case of highly porous limestone (Valhall, Ekofisk),
  - in case of highly porous sandstones
  - in case of highly porous diatomite (Wilmington)

# Subsidence modeling



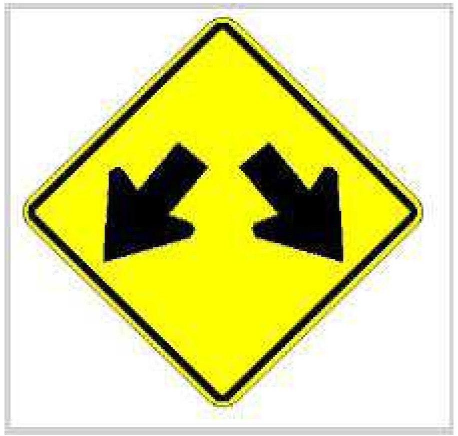
# Time dependence

- production changes over time,
- porosity depends on effective stress,
- effective stress depends on pore pressure depletion,
- compaction depends on porosity,
- subsidence depends on compaction,
- subsidence depends on the delay conditions of overburden…

# What else…

?

# Possible ways to subsidence prediction



Sophisticated modeling

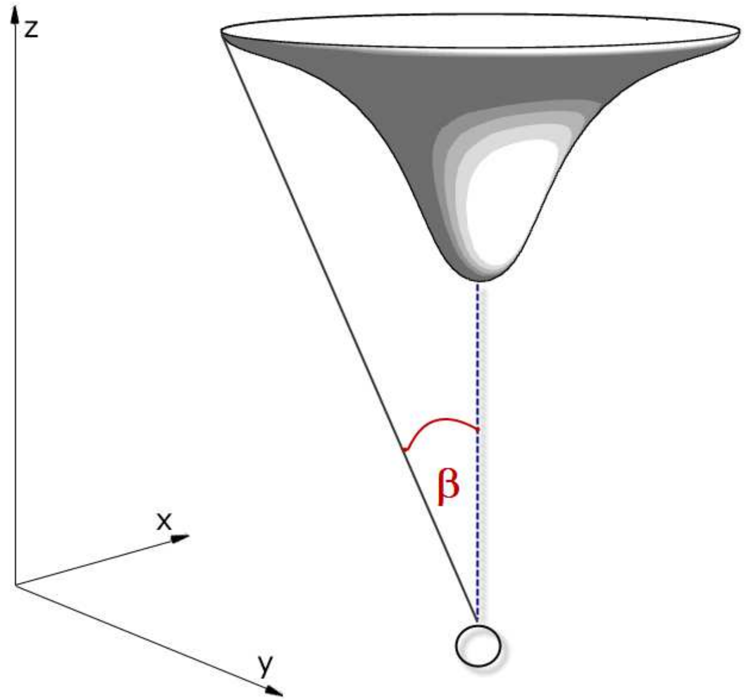
Simple modeling

# Simple modeling of surface subsidence

- It means:
  - significant generalization of the reality,
  - simple and fast calculation of the subsidence in 3D,
  - few model parameters (easily estimated),
  - relatively high accuracy.

# Assumptions…

- range of the subsidence trough depends on one parameter



# Assumptions...

- Time delay between production and compaction

...but it is not so easy

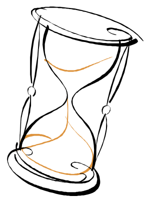
# Modeling of the time dependent phenomenon..

production → anticipated compaction

~~$p_0 - p(t)$ → Final compaction $K^E(t)$~~

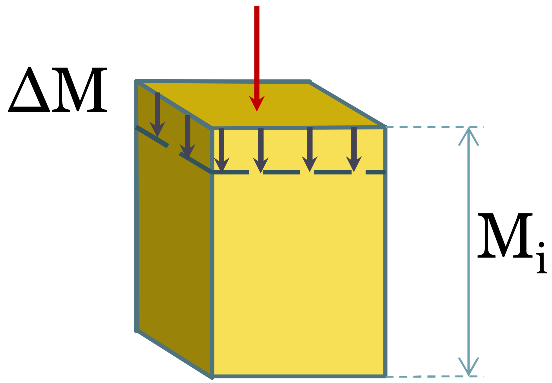
$p_0 - p(t)$ → real compaction $K(t)$

**time delay**



$K^E(t)$

# Compaction - change of the reservoir thickness



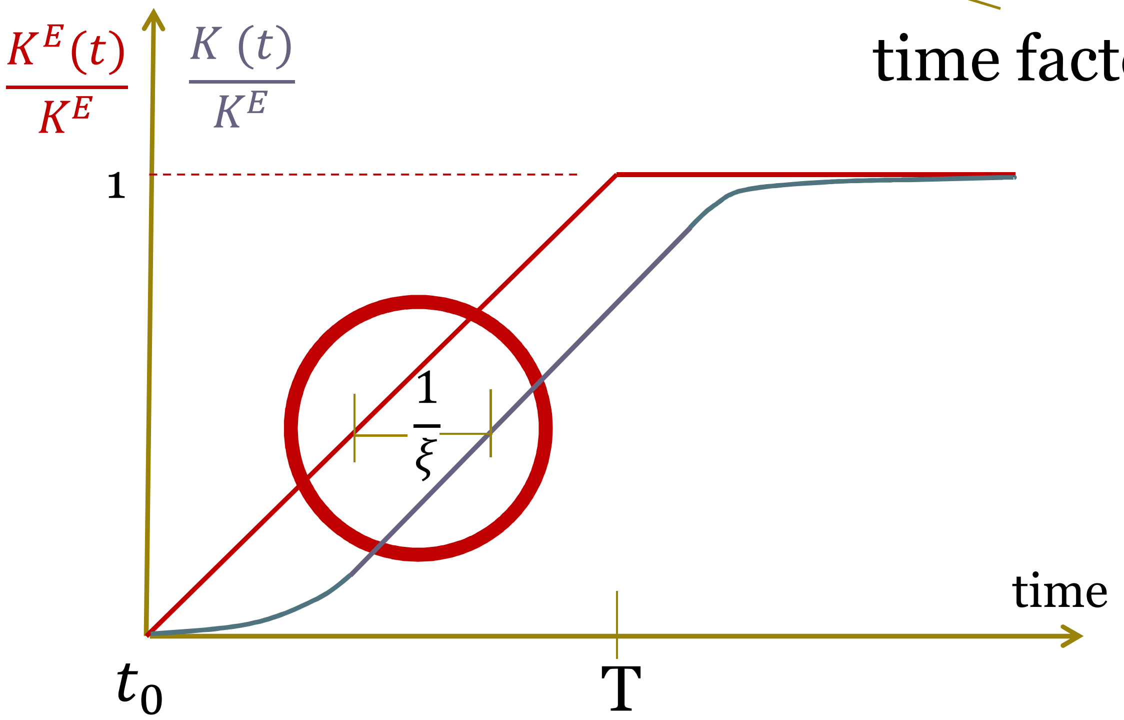

$$\Delta M_i = c_m \cdot \Delta p_i \cdot M_i$$

$$K^E = \frac{\Delta M}{M}$$ final, uniaxial compaction

$$K^E(t) = c_m[p_0 - p_E(t)]$$

$$\frac{\partial K(t)}{\partial t} = \xi\left[K^{E}(t) - K(t)\right]$$

time factor - reservoir

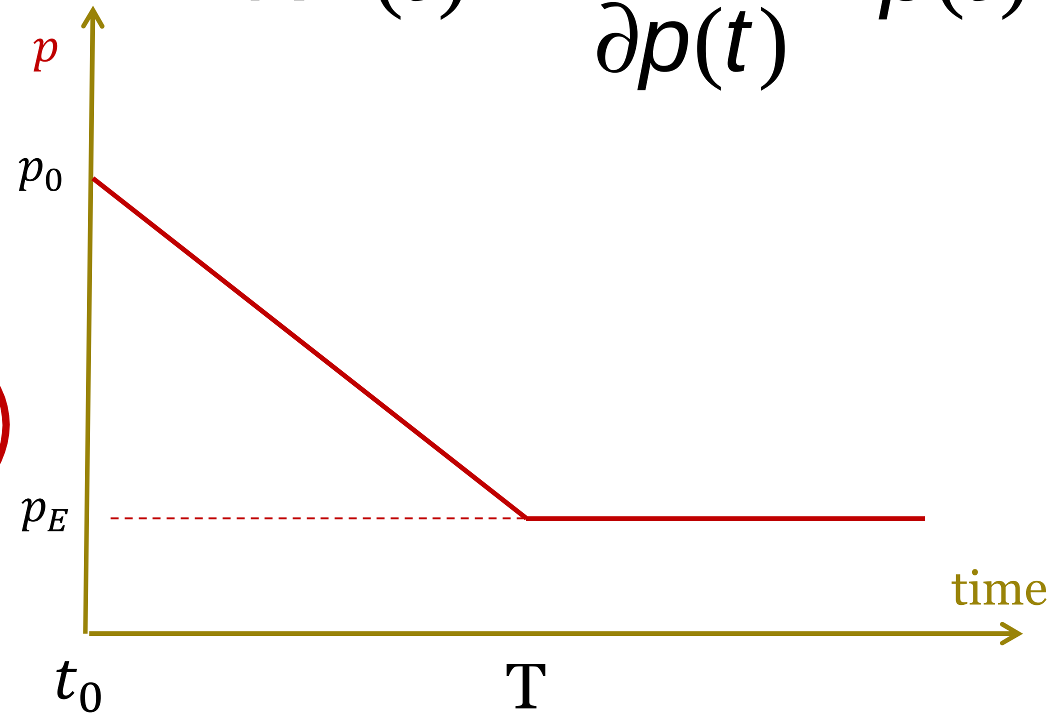


# general solution:

$$K(t) = K^E(t) - \exp(-\xi \cdot t) \cdot \int_0^t \dot{K}^E(\lambda) \cdot \exp(\xi \cdot \lambda) d\lambda$$

$$\dot{K}^E(t) = \frac{\partial K^E(t)}{\partial p(t)} \cdot \dot{p}(t)$$

$$\dot{K}^E(t) = -c_m \cdot \dot{p}(t)$$



# Compaction volume

$$V_K(t) = K(t) \cdot V$$

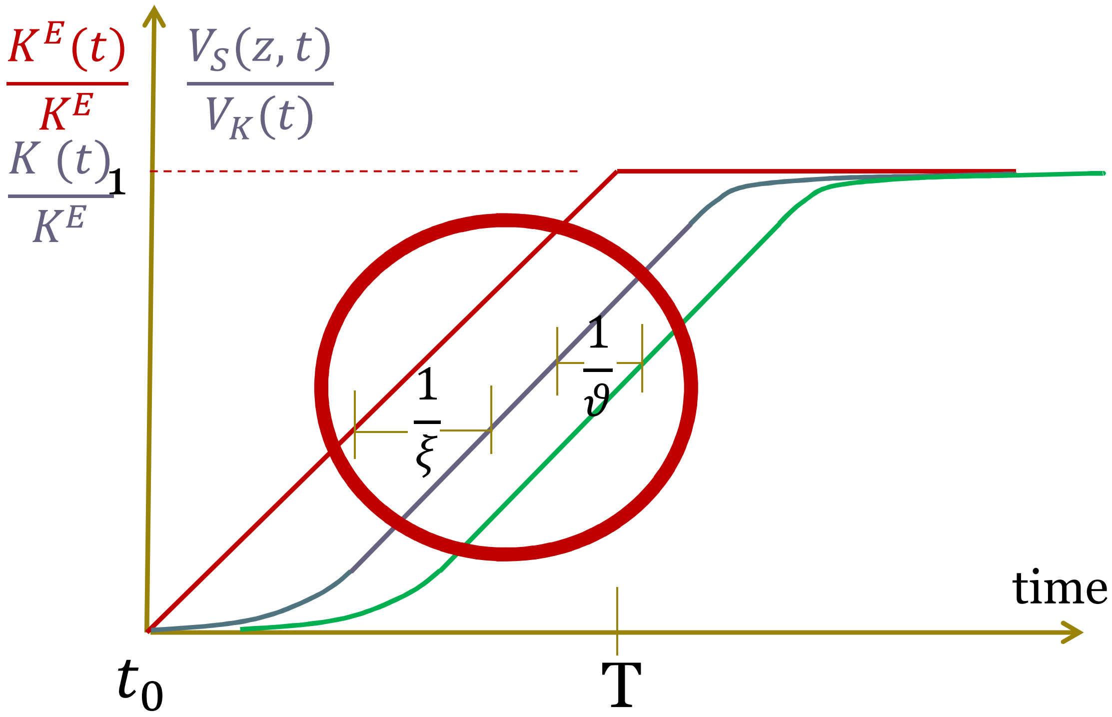
Volume of one reservoir element

# Assumptions…

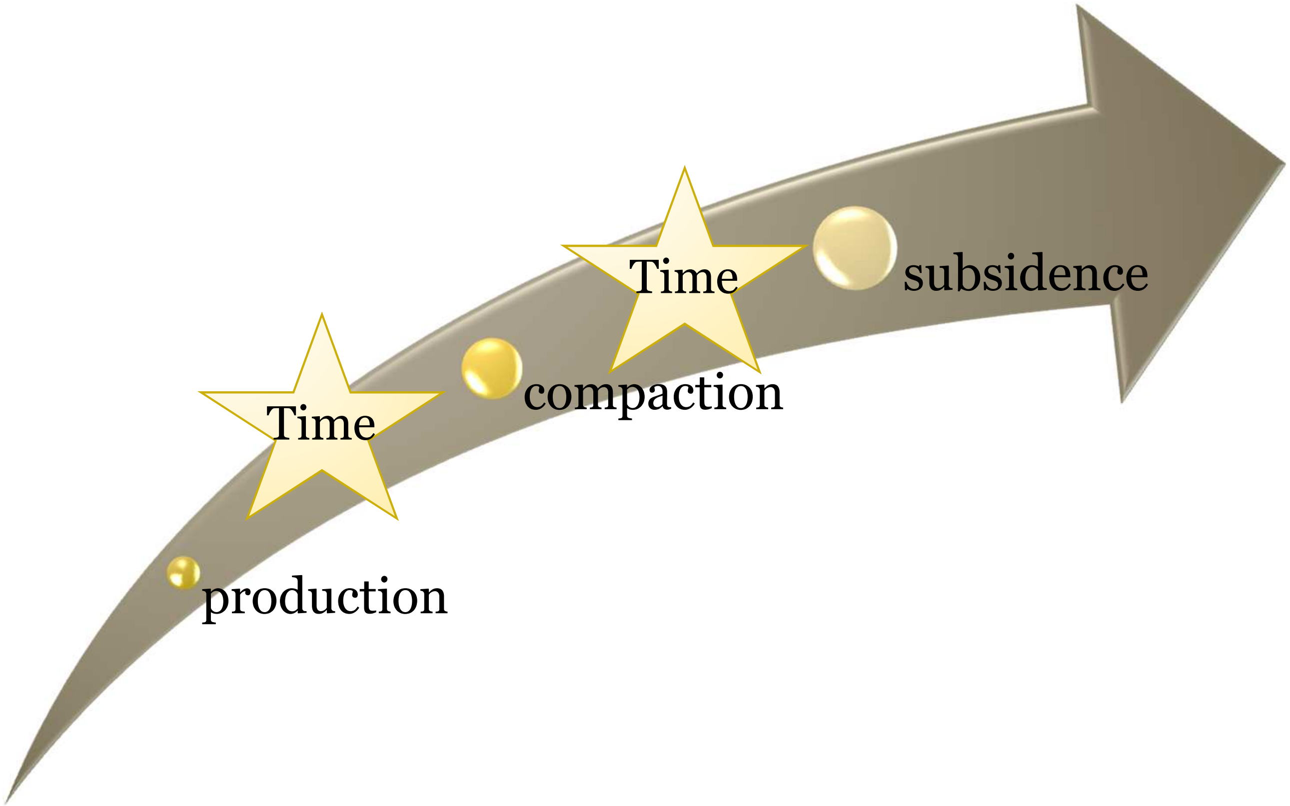
- Time delay between compaction and subsidence

$$\frac{\partial V_S(z,t)}{\partial t} = \vartheta\left[V_K(t) - V_S(z,t)\right]$$

time factor - overburden



# Subsidence prediction – simplest way



# Generalization of the reservoir shape…