Time-lapse gravity response of compacting reservoirs

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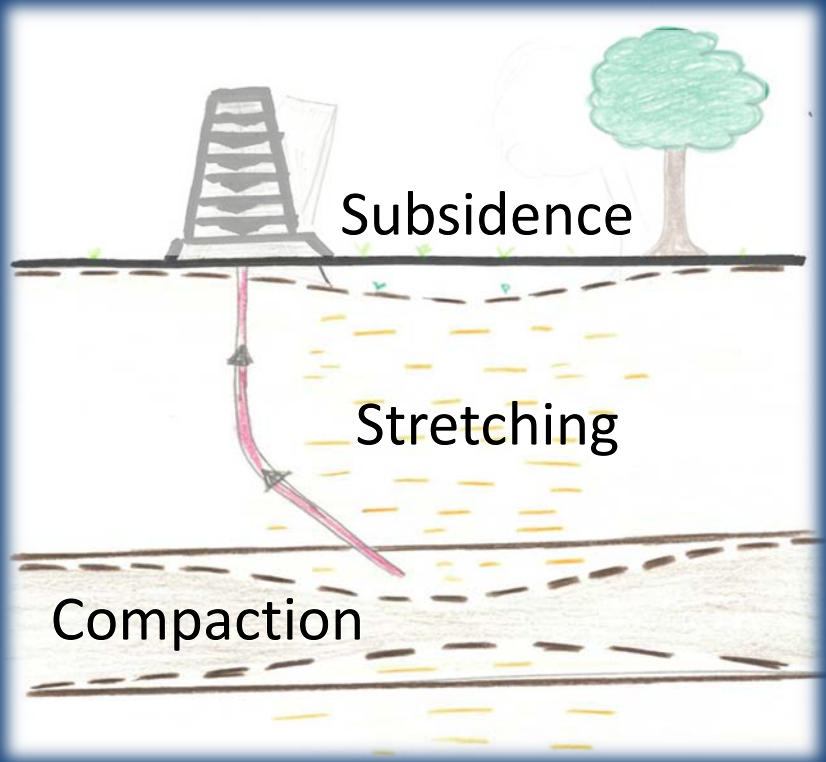
Objective

Can 4D gravity detect compaction?

Contents:

- 4D Gravity
- Forward modelling
- Results of synthetic case



Time-lapse gravity

- Newton's law of gravitation:

$$g_z = G \cdot m \cdot \frac{z}{r^3}$$

- Fluid substitution: if $\rho_{f2} \geq \rho_{f1}$

$$m_2 \geq m_1$$

Troll field (Eiken et al, 2008)

- 4D gravity repeatability: **4 µGal**
- **9 µGal** of 4D signal: 2.8 m water rise
- Max subsidence: 3 cm change in density?

Monitoring compaction

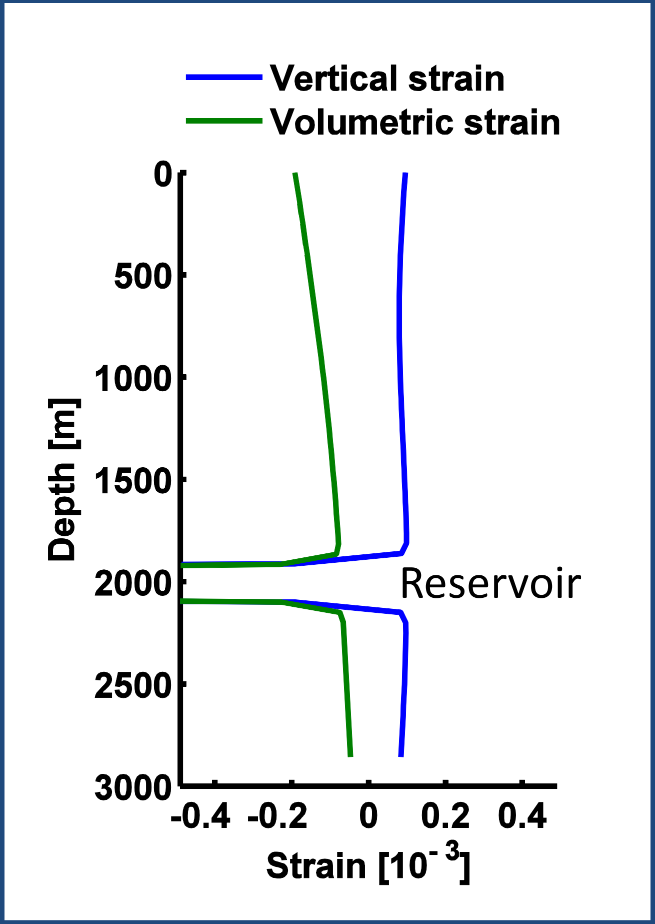
Compacting reservoir → Δ stress, Δ strain

4D seismic: $$\frac{\Delta T}{T} = \frac{\Delta z}{z} + \frac{\Delta V}{V}$$

4D gravity: $$\Delta g_z = f(\Delta \rho)$$

Valhall:

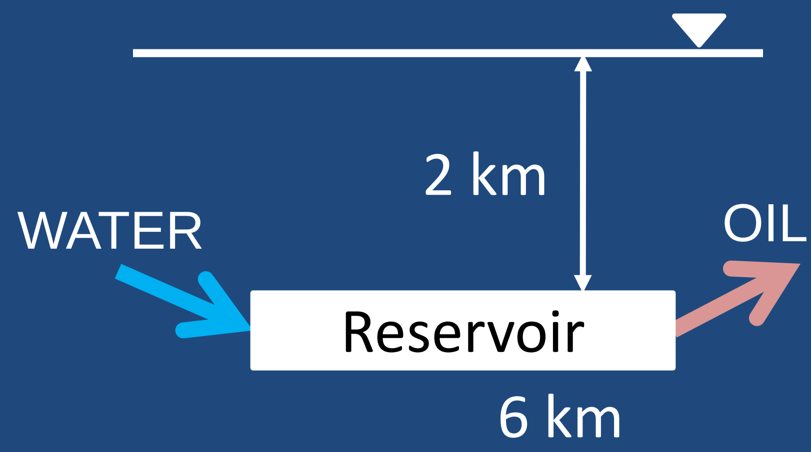
- Overburden = 0.7 millistrain
- Reservoir = 130 millistrain
- Time-shift = 20 ms



Forward modelling

1. Volumetric strain estimation
2. Density change estimation
3. Time-lapse gravity modelling

Synthetic model



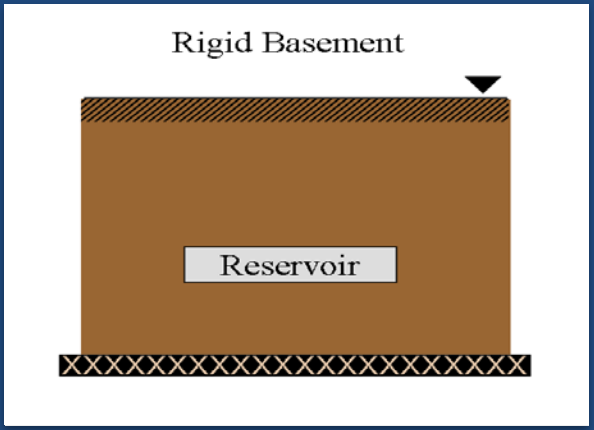
ΔP = 10 MPa	C_m = 10^{-3} Mpa^{-1}
ϕ = 20-30 %	ν = 0.25

1 - Volumetric strain estimation

3D analytical model:

- Geertsma's method
- Rigid basement extension

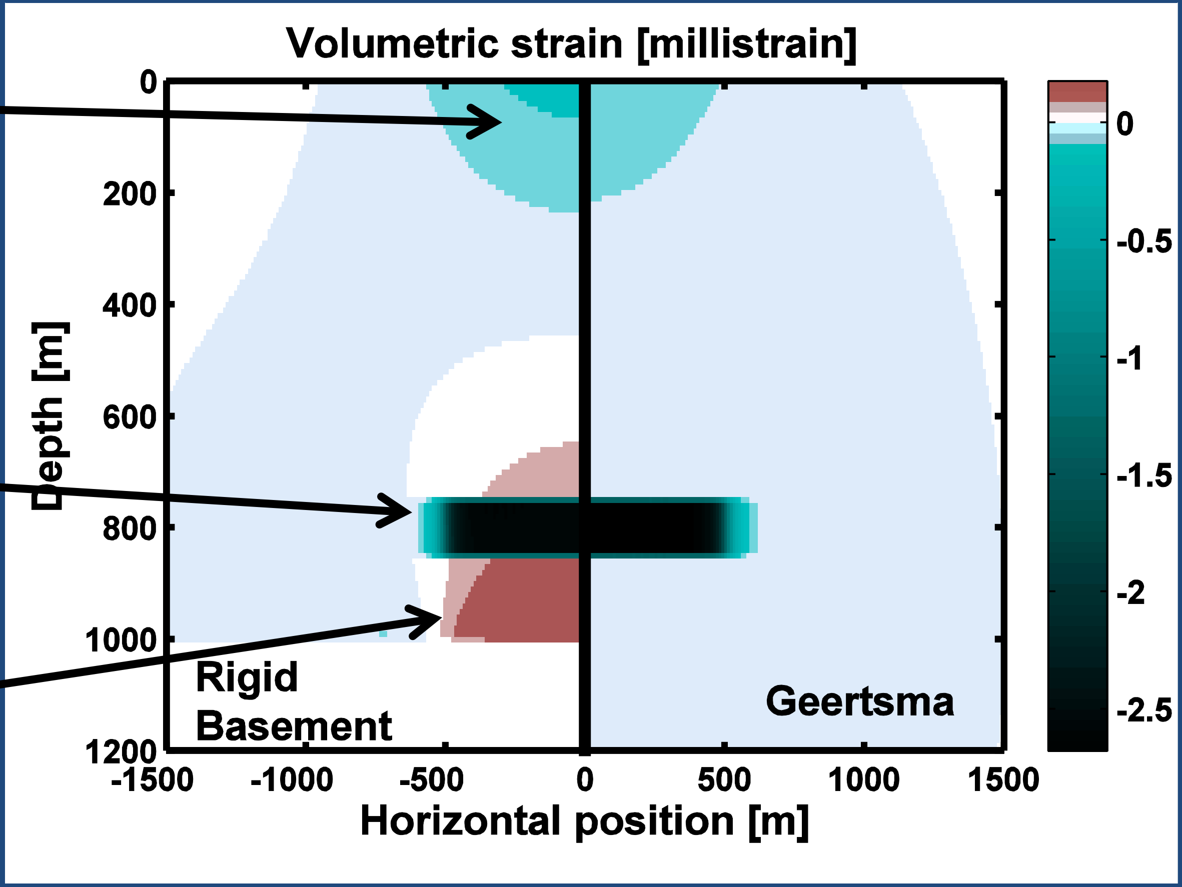
- Nucleus of strain approach
- Homogeneous material
- Linear elastic behaviour



Shallow rock volume decrease

Reservoir volume decrease

Rock volume increase around reservoir



2 - Density change estimation

Density change:

$$\Delta\rho = \left(\rho_f - \rho_s\right) \cdot \Delta\phi$$

where

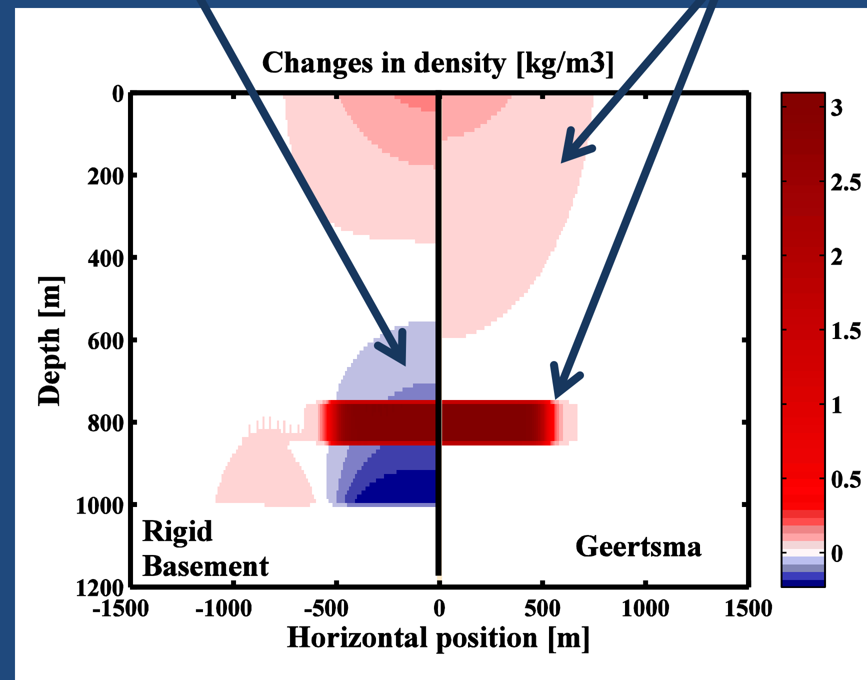
$$\Delta\phi = (1 - \phi_{ini}) \cdot \varepsilon_{vol}$$

and

$$\varepsilon_{vol} = \varepsilon_x + \varepsilon_y + \varepsilon_z$$

Estimated density change:

- Density decrease
- Density increase



3 – Time-lapse gravity modelling

- Gravity effect of element volume after production

$$g_{z,n,monitor} = G \cdot (\rho + \Delta\rho) \cdot (V + \Delta V) \cdot \frac{(z + \Delta z)}{R_{defor}^3}$$

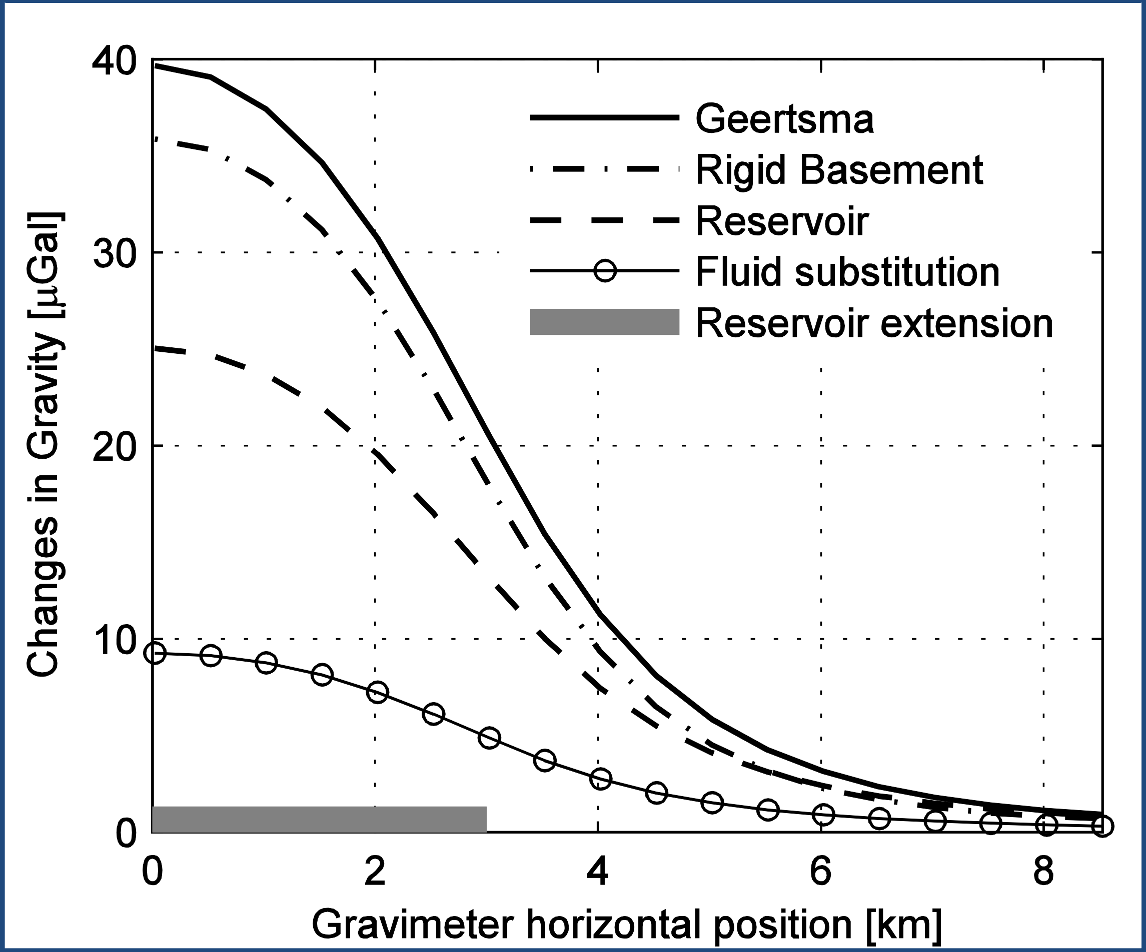
- Time-lapse effect of element volume

$$\Delta g_{z,n} = g_{z,n,monitor} - g_{z,n,base}$$

- Total time-lapse effect

$$\Delta g_z = \sum_{n=1}^{N} \Delta g_{z,n}$$

4D gravity effect



10 millistrain

\+

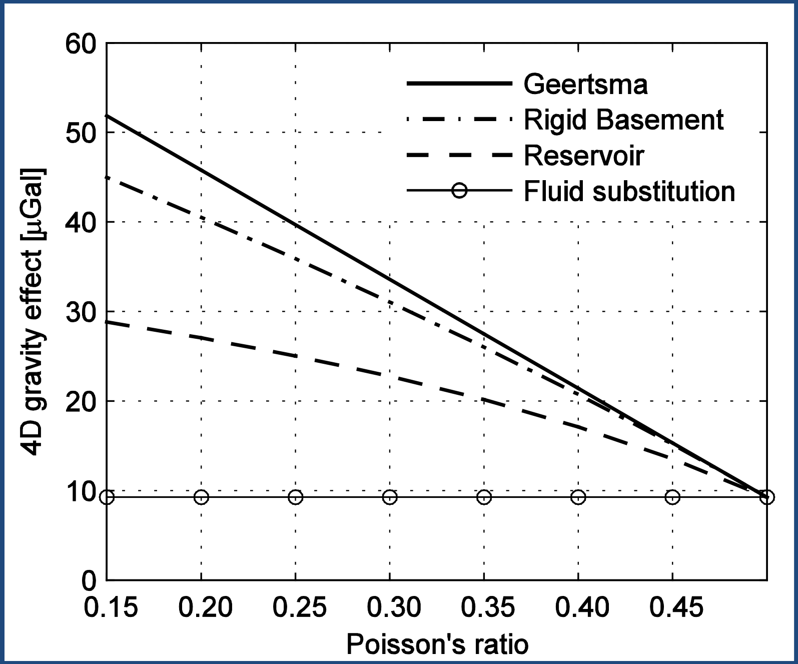
10 m water→oil

↓↓

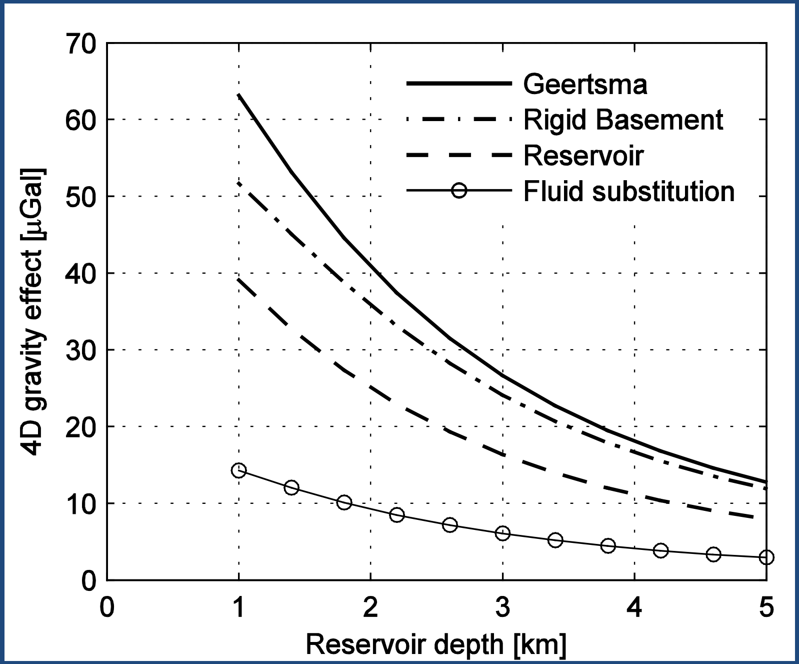
40 μGal

Sensitivity

Poisson's ratio



Reservoir depth



Conclusion

- Forward model for 4D gravity anomaly changes due to compacting reservoirs
- Predicted anomaly changes (30-40 µGal) greater then current (4 µGal) accuracy
- Deformation of surroundings accounted for 15 – 25 % of predicted 4D gravity effect

Acknowledgement

TOTAL

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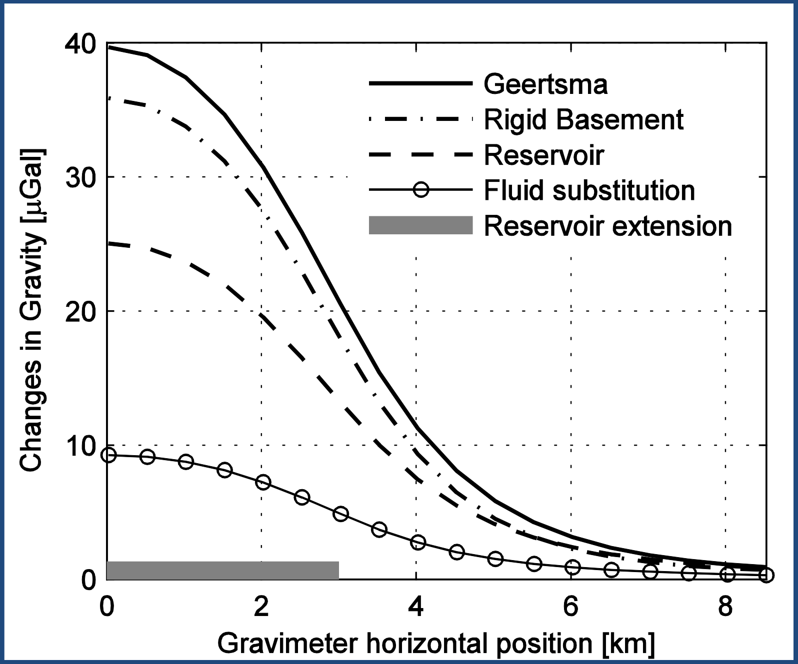

THANK YOU FOR YOUR ATTENTION!
ANY QUESTION?