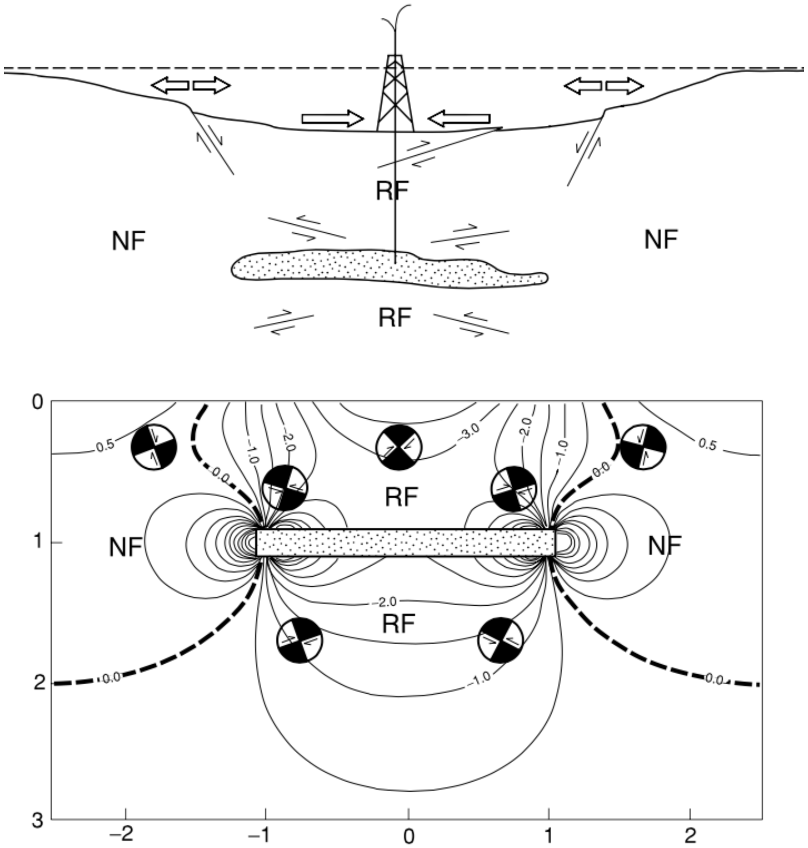
Reservoir Depletion

Effects of reservior depletion



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Estimating stress changes in depleting reserviors

$$S_{Hor} = S_{Hmax} = S_{hmin} = \frac{\nu}{1-\nu} S_v + \alpha P_p \left(1 - \frac{\nu}{1-\nu}\right)$$

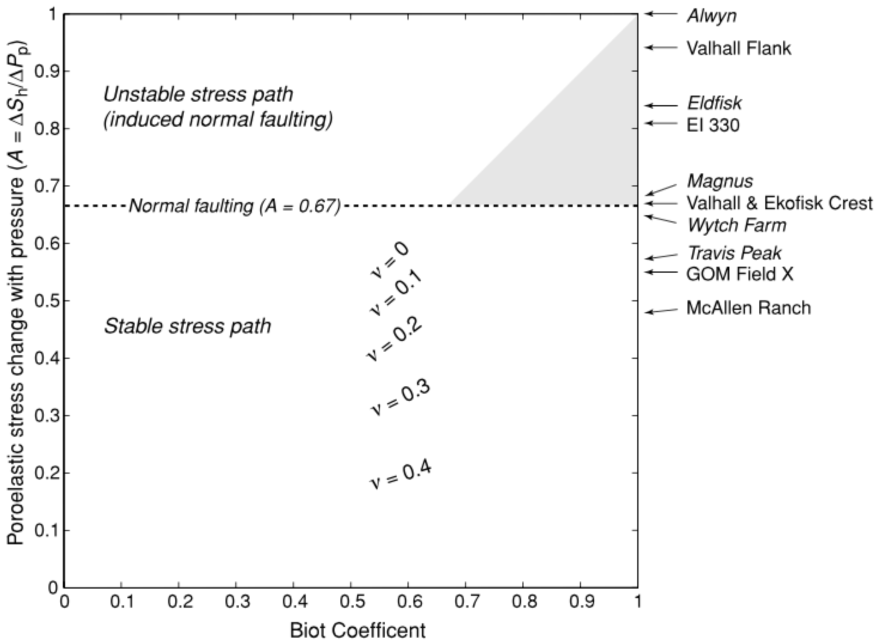
$$\frac{\mathrm{d}S_{Hor}}{\mathrm{d}P_p} = \alpha \frac{1-2\nu}{\nu-1} \qquad \text{during production}$$

$$\Delta S_{Hor} = \alpha \frac{1-2\nu}{\nu-1} \Delta P_p$$

Taking $\nu = \frac{1}{4}$ and $\alpha = 1$

$$\Delta S_{Hor} \sim \frac{2}{3} \Delta P_p$$

Comparison of theory and observation



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Production induced faulting

$$\frac{S_v - (Pp - \Delta P_p)}{(S_{hmin} - \Delta S_{hmin}) - (Pp - \Delta P_p)} = (\sqrt{\mu^2 + 1} + \mu)^2$$

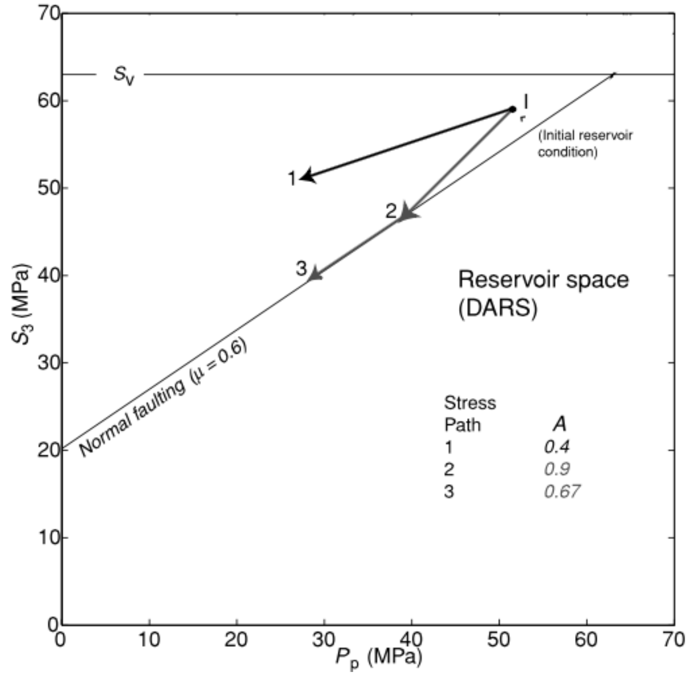
Simplification leads to

$$\frac{\Delta S_{Hmin}}{\Delta P_p} = 1 - \frac{1}{(\sqrt{\mu^2 + 1} + \mu)^2}$$

For $\mu = 0.6$

$$\frac{\Delta S_{Hmin}}{\Delta P_p} = 0.67$$

Reservoir space plot



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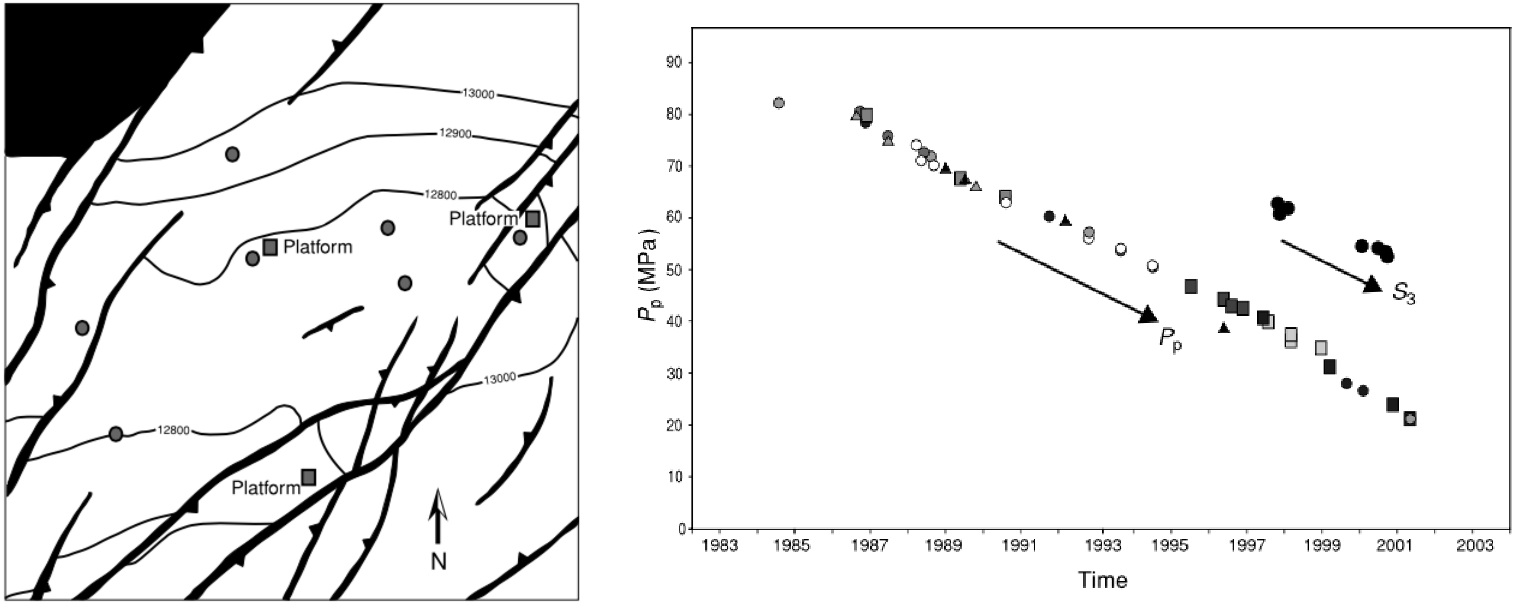
GOM Field X



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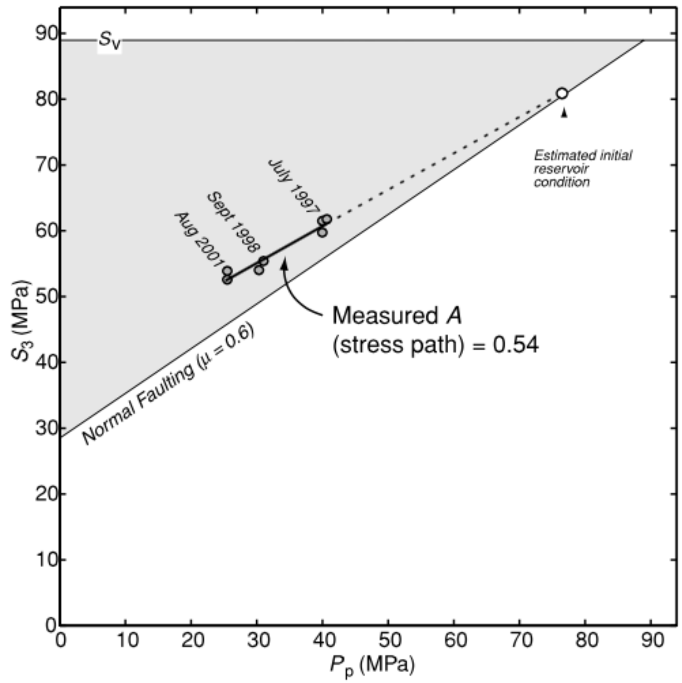

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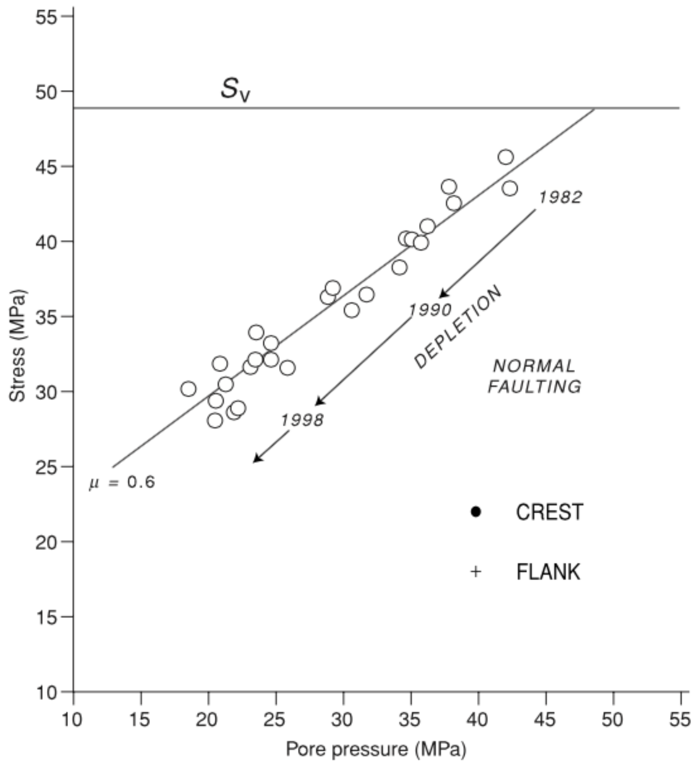
Valhall field in North Sea



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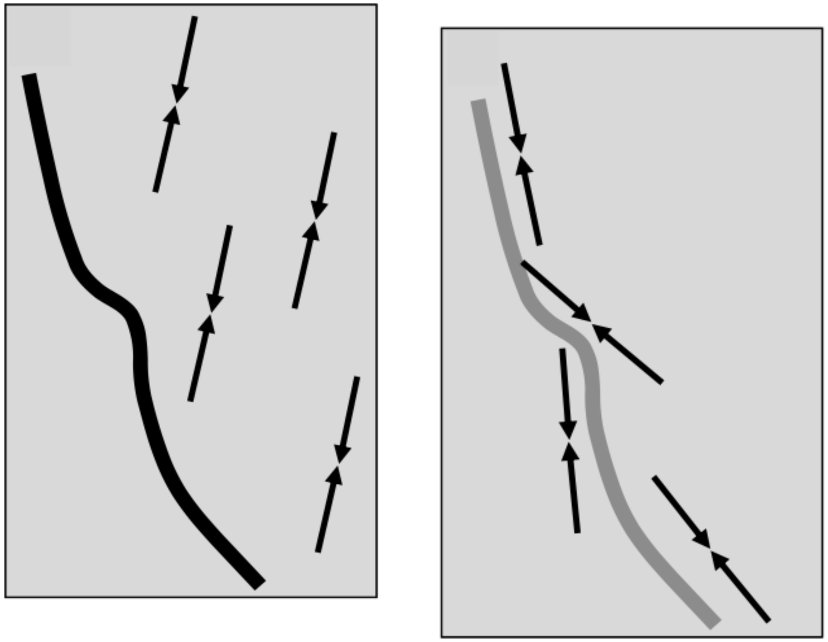
Stress rotations with depletion



Original Depleted

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Rotation angle, $\boldsymbol{\gamma}$ near the fault due to depletion

$$\gamma = \frac{1}{2}\tan^{-1}\left(\frac{Aq\sin(2\theta)}{1 + Aq\cos(2\theta)}\right)$$

with

$$A = \frac{\Delta S_{hmin}}{\Delta P_p}$$

and

$$q = \frac{\Delta P_p}{S_{Hmax} - S_{hmin}}$$

Deformation in depleting reservoirs

Subsidence

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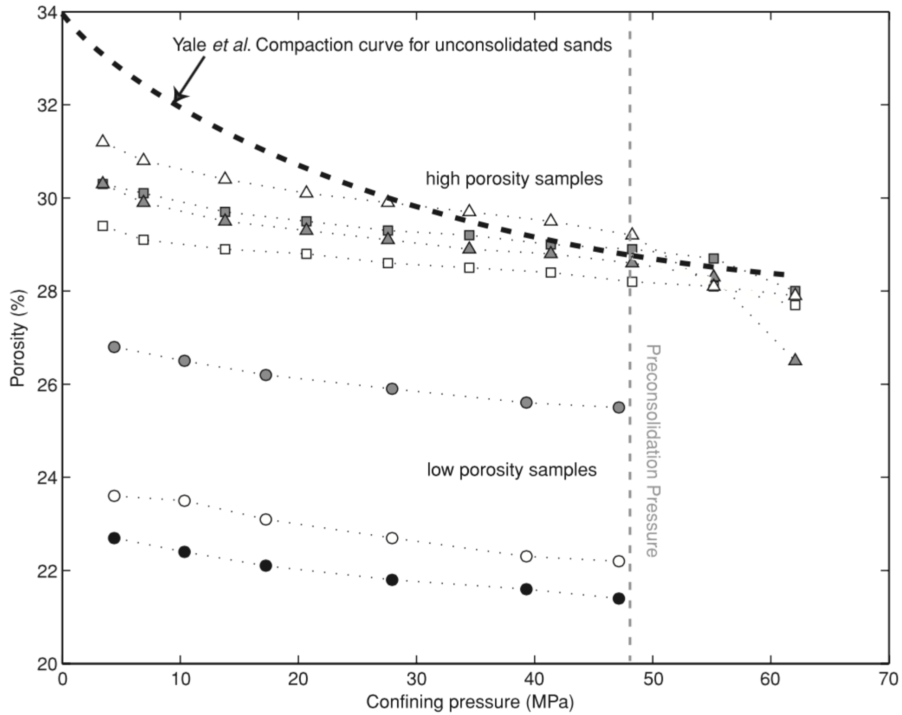
Recall: Compaction curves



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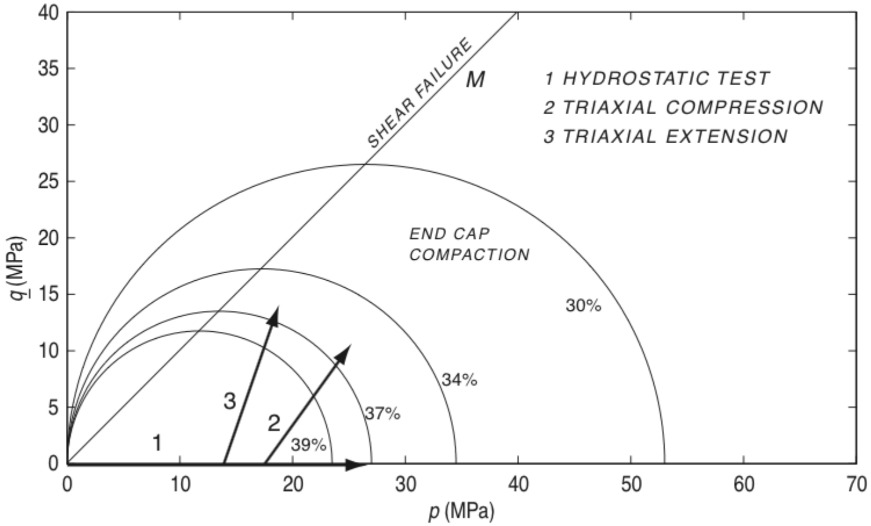
Recall: End-cap models



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$$p = \frac{1}{3}(S_1 + S_2 + S_3) - P_p$$

$$q^2 = \frac{1}{2}\left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_1 - S_3)^2\right)$$

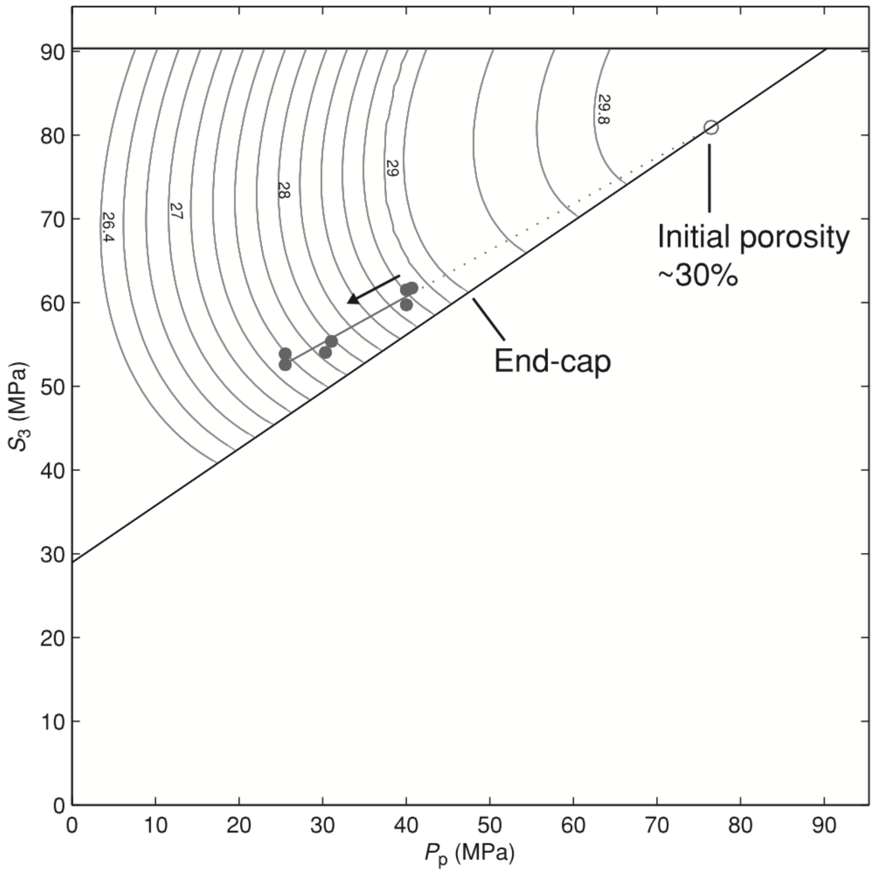
$$M^2 p^2 - M^2 p_0 p + q^2 = 0$$

$$
\begin{aligned}
9P_p^2 &+ \left(1 + \frac{9}{M^2}\right)(S_v^2 + S_{Hmax}^2 + S_{hmin}^2) \\
&+ \left(2 - \frac{9}{M^2}\right)(S_v S_{Hmax} + S_v S_{hmin} + S_{Hmax} S_{hmin}) \\
&+ 9P_p p_0 - 3(2P_p + p_0)(S_v + S_{Hmax} + S_{hmin}) = 0
\end{aligned}
$$

$$M = \frac{6\mu}{3\sqrt{\mu^2 + 1} - \mu}$$

From Mohr-Coulomb assuming C_0 is negligible

Deformation Analysis in Reservoir Space (DARS) model of GOM Field X



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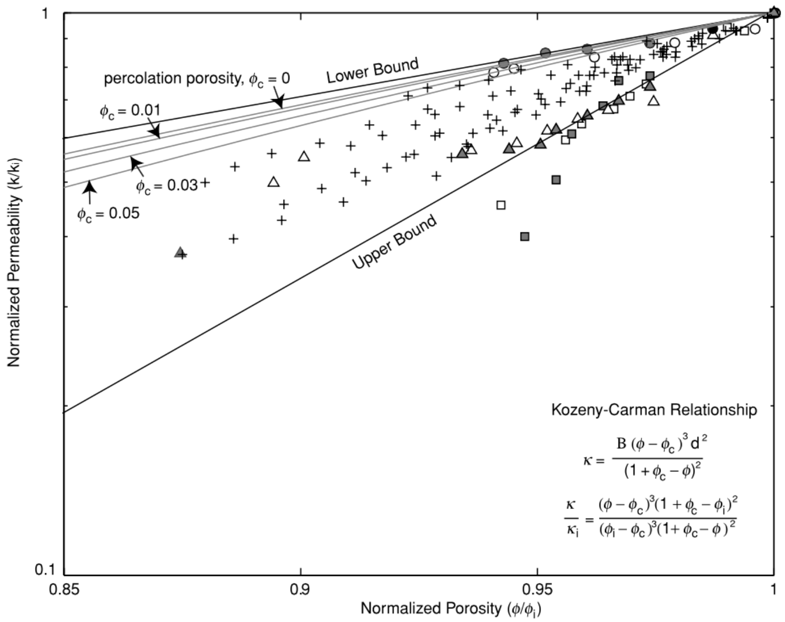
Permeability change as a function of porosity change



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Modified Kozeny-Carman relationship

$$\kappa = B\frac{(\phi - \phi_c)^3}{(1 + \phi_c - \phi)^2}d^2$$

For change in permeability

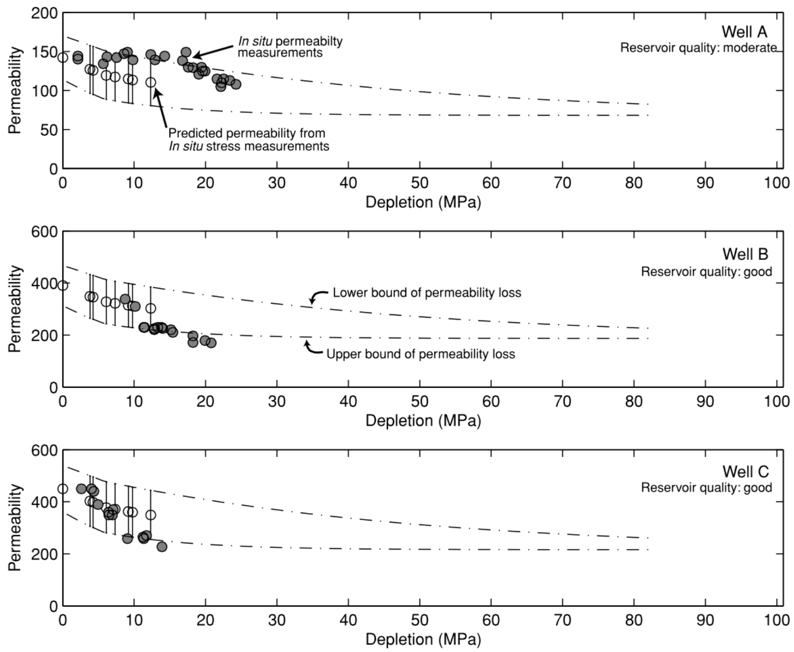
$$\frac{\kappa}{\kappa_i} = \left(\frac{\phi - \phi_c}{\phi_i - \phi_c}\right)^3 \left(\frac{1 + \phi_c - \phi_i}{1 + \phi_c - \phi}\right)^2$$

Including a factor for grain size reduction

$$\Gamma = \frac{1 - d/d_i}{1 - \phi/\phi_i}$$

$$\frac{\kappa}{\kappa_i} = \left(\frac{\phi - \phi_c}{\phi_i - \phi_c}\right)^3 \left(\frac{1 + \phi_c - \phi_i}{1 + \phi_c - \phi}\right)^2 \left(1 - \Gamma\left(1 - \frac{\phi}{\phi_i}\right)\right)$$

Permeability loss with depletion in GOM Field Z



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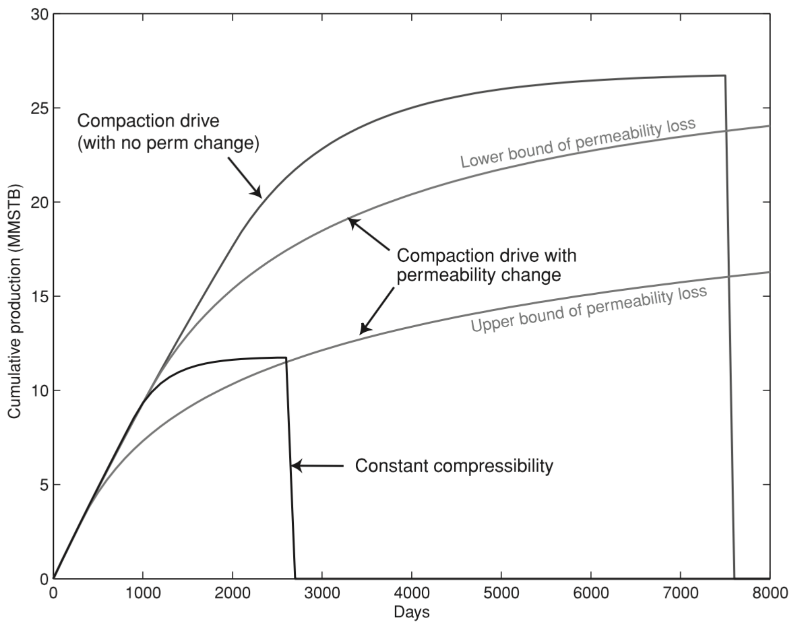
Idealized resevoir study



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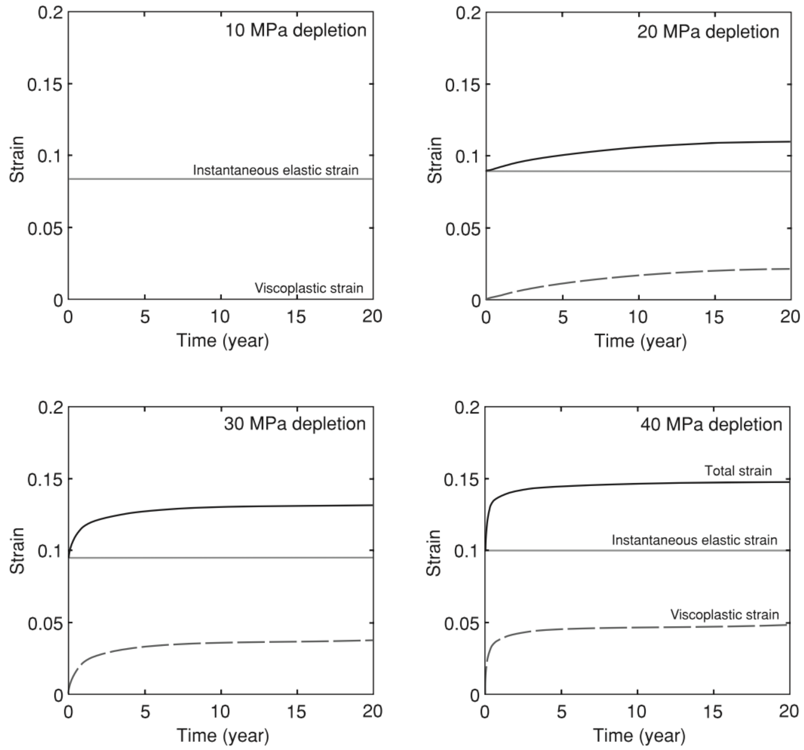
Viscous compaction in GOM Field Z



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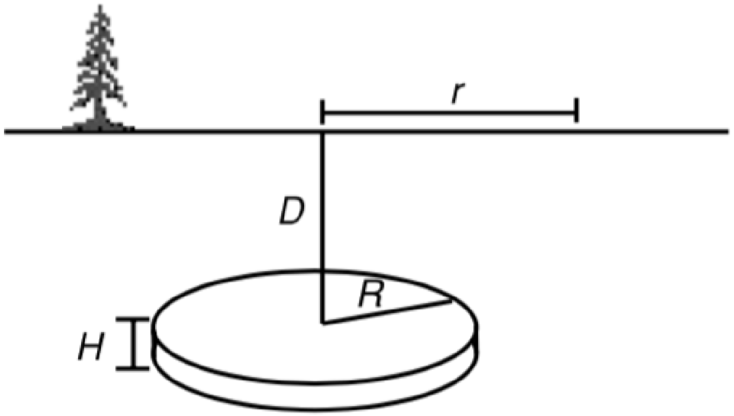
Geertsma (1973) dispacement solution

$$u_z(r,0) = -\frac{1}{\pi} c_m (1-\nu) \frac{D}{\left(r^2 + D^2\right)^{3/2}} \Delta P_p V$$

$$u_r(r,0) = +\frac{1}{\pi} c_m (1-\nu) \frac{D}{\left(r^2 + D^2\right)^{3/2}} \Delta P_p V$$



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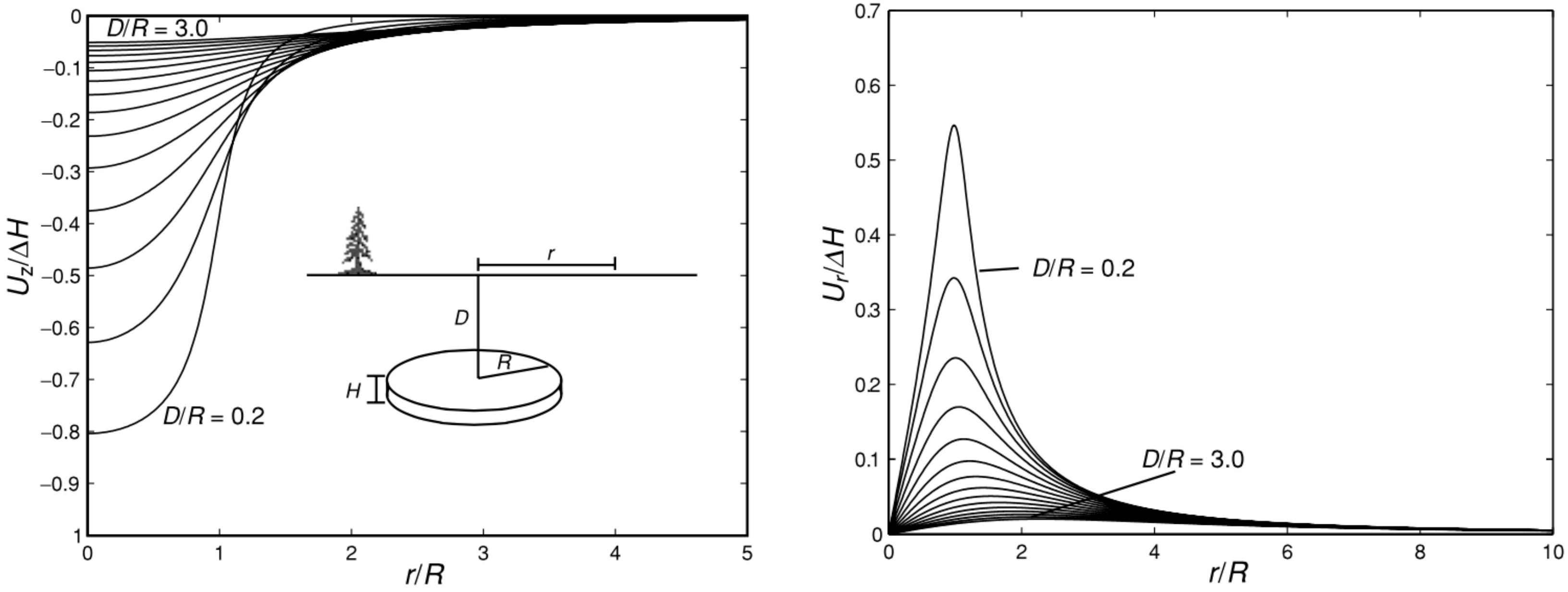
Subsidence and horizontal dispacement



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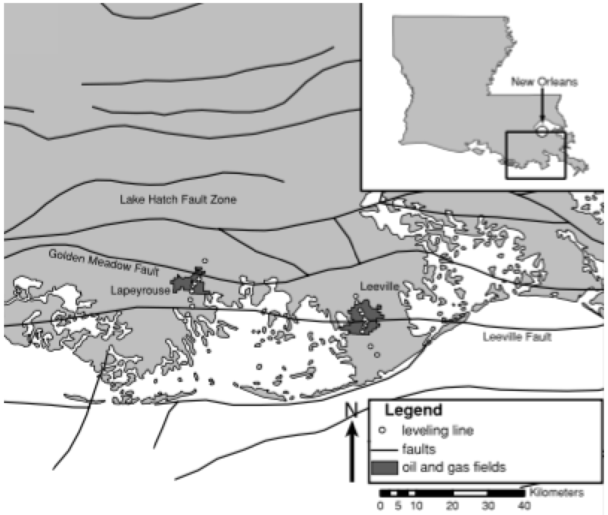
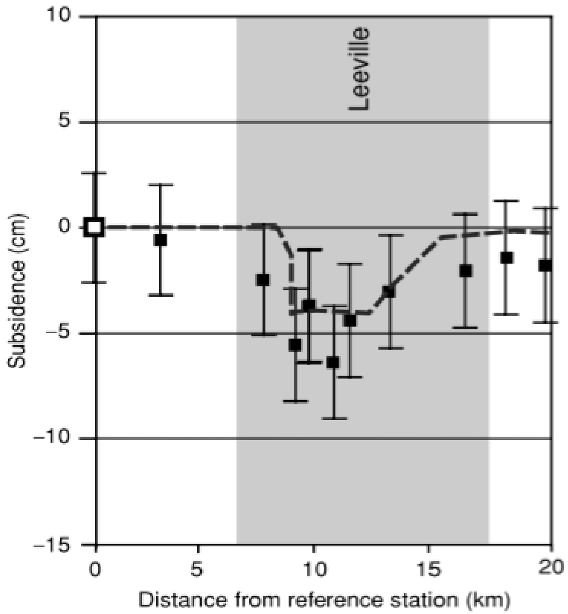
Leeville case study





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