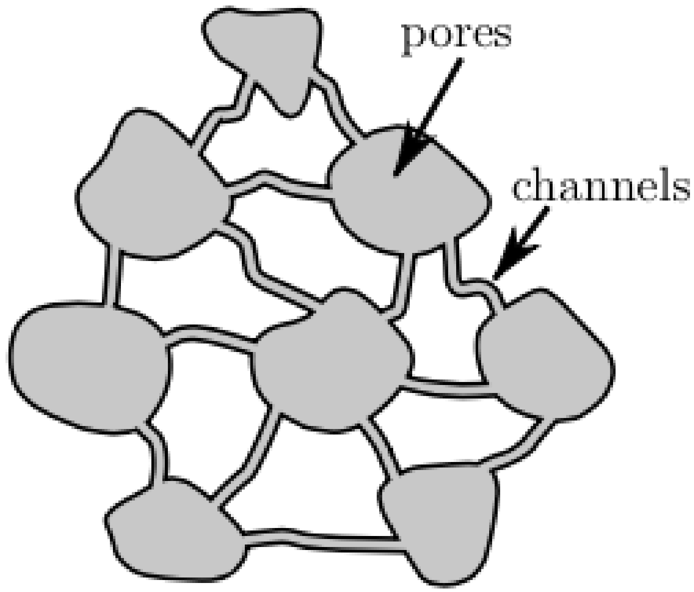
Effective stress



Effective stress tensor

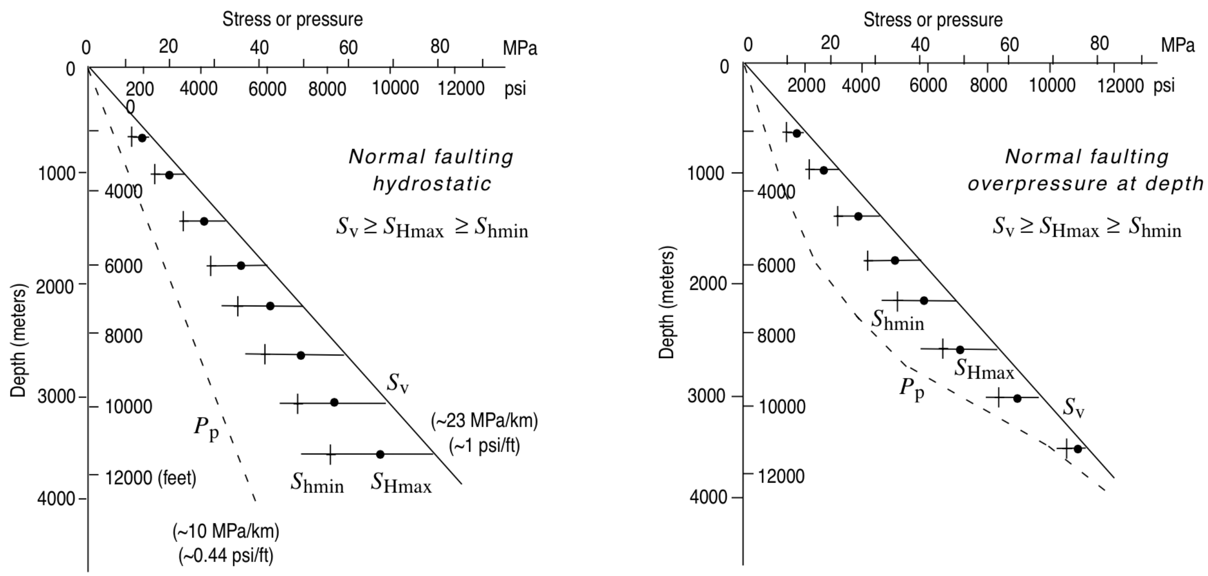
$$\boldsymbol{\sigma}_{eff} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} - \begin{bmatrix} P_p & 0 & 0 \\ 0 & P_p & 0 \\ 0 & 0 & P_p \end{bmatrix}$$

$$\boldsymbol{\sigma}_{eff} = \begin{bmatrix} S_{11} - P_p & S_{12} & S_{13} \\ S_{12} & S_{22} - P_p & S_{23} \\ S_{13} & S_{23} & S_{33} - P_p \end{bmatrix}$$

- Faulting depends on the effective stress

Stress magnitudes at depth

Normal faulting

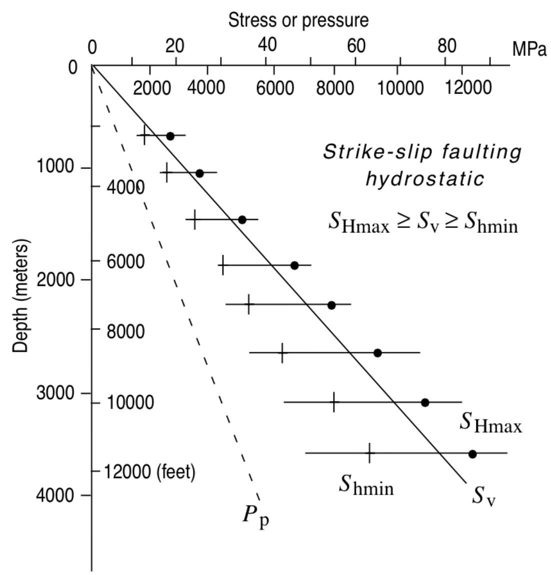


Hydrostatic

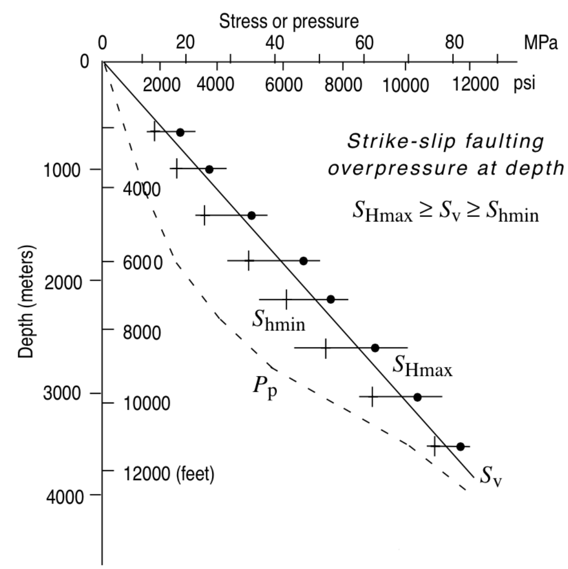
Overpressure

 Zoback (Fig. 1.4, pp. 13)

Strike-slip faulting

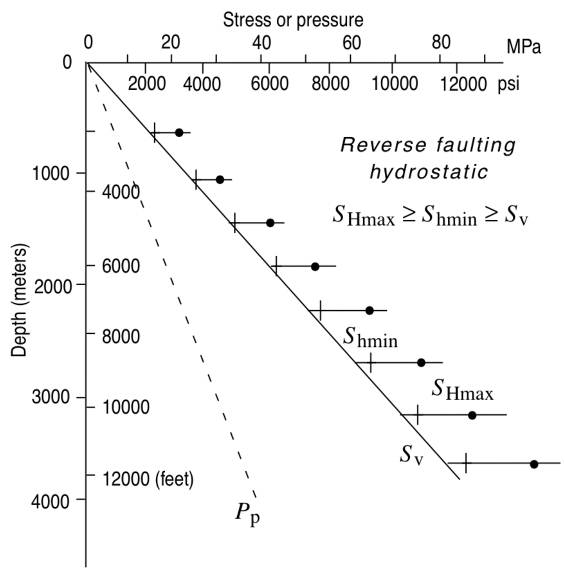


Hydrostatic

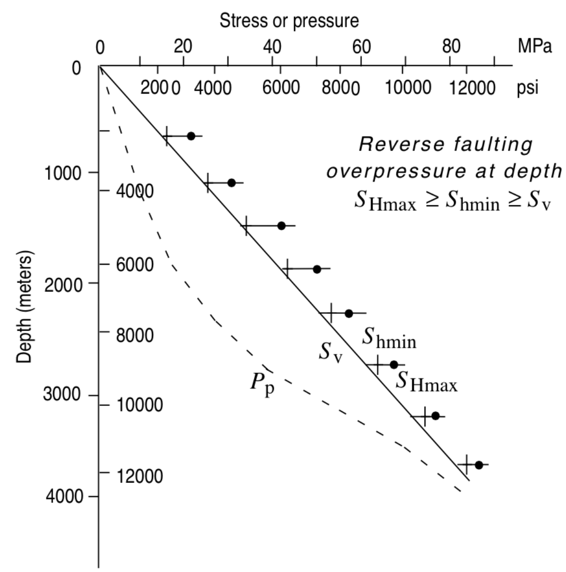


Overpressure

Reverse faulting



Hydrostatic



Overpressure

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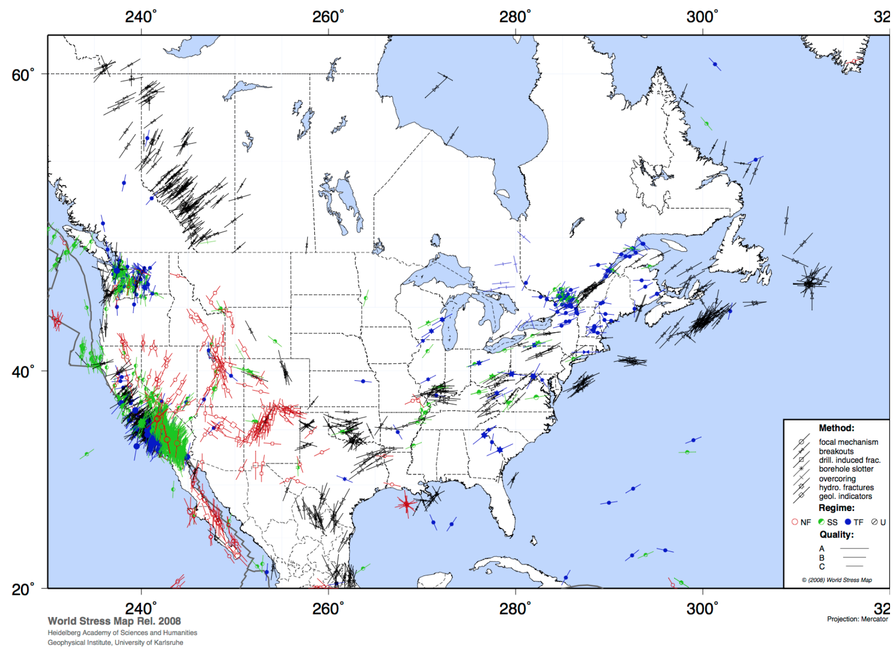
Stress measurement techniques

- S_v - integration of density logs
- S_3 (S_{hmin}, except in reverse faulting) is obtained from mini-fracs and leak-off tests. Zoback (Chapter 6)
- P_p measure directly or estimated from geophysical logs or siesmic data. Zoback (Chapter 2)
- Bound S_{Hmax} with frictional strength of crust or oberservations of wellbore failures. Zoback (Chapter 4, 7, 8)
- Orientation of principal stresses from wellbore observations, geology, earthquake focal mechanisms. Zoback (Chapter 5, 6)

Stress maps



Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., and Müller, B., The World Stress Map database release 2008 DOI:10.1594/GFZ.WSM.Rel2008, 2008

Pore pressure at depth

$$P_p^{\text{hydro}} = \int_0^z \rho_w(z) g \mathrm{d}z \approx \rho_w g z_w$$

Ratio of pore pressure to $\mathbf{S_v}$

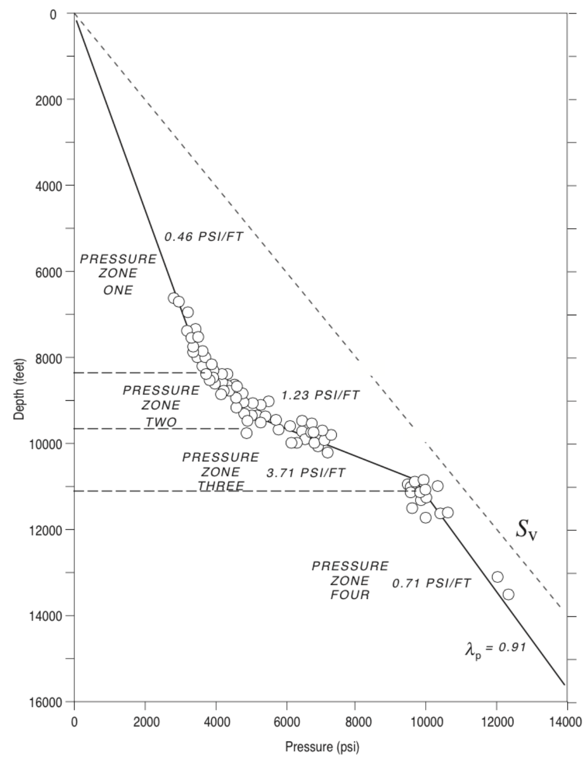
$\lambda_p = P_p/S_v$

Hydrostatic: $\lambda_p \approx 0.44$

Lithostatic: $\lambda_p = 1$

Overpressure

Monte Cristo field (onshore near Gulf of Mexico, Texas)



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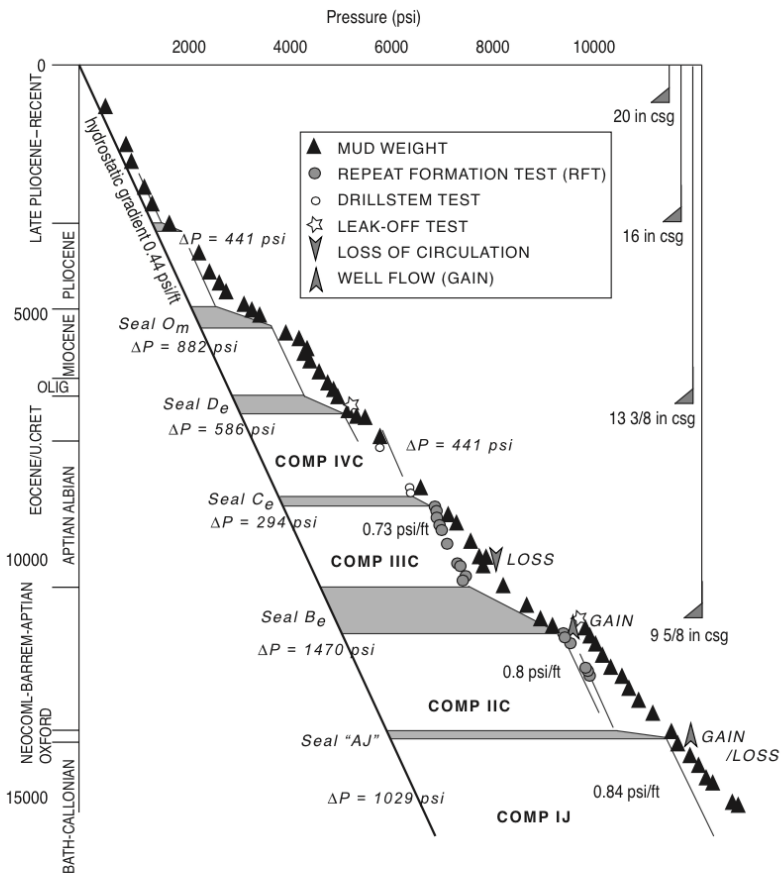
Reservior Compartmentalization



Mechanisms of overpressure

Disequilibrium compaction

- Ongoing sedimentation increases overburden (vertical stress) faster than fluid diffuses out of zone

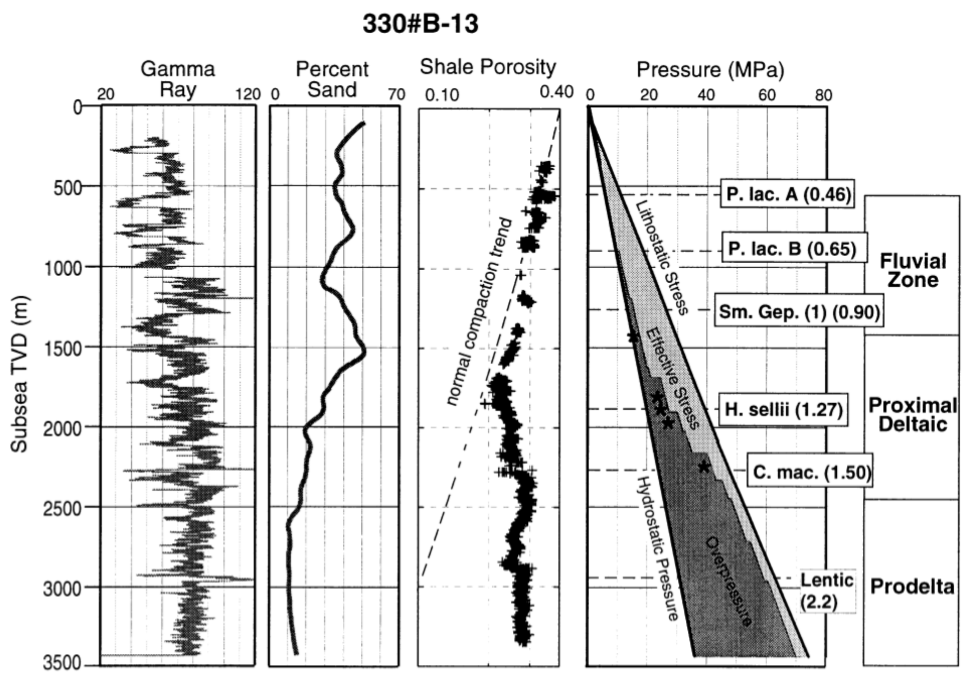
Characteristic time of diffusion in porous medium

$$\tau = \frac{(\phi\beta_f + \beta_r)\eta l^2}{k}$$

- low-permiability sand (~1 md)
  - τ on the order of years for $l = 0.1\,\mathrm{km}$

- low-permiability shale (~10 nd)
  - τ on the order of 100,000 years for $l = 0.1\,\mathrm{km}$

Common in Gulf of Mexico



 Gordon and Flemmings, 1998