Subsurface Pressure and Stress

Geol493K

Stress

Stress = force / area

Units = Pascals, psi

= N/m^2

$= kg/(m \cdot s^2)$

Force= 50 kg * 9.8 m/s^2

Area = 1 cm^2 = 0.0001 m^2

Stress = 4,900,000 Pascals
686 psi

How much is 1 Pascal?

- 1 Pa= 0.00014 psi
- Car tire ~230,000 Pa
- 1 Megapascal (1 MPa) = 1 million Pa
  = 1 x 10^6 Pa
  = 145 psi

Stress/pressure

•What is the difference?

•Pressure - Scalar quantity
•Stress - Tensor quantity

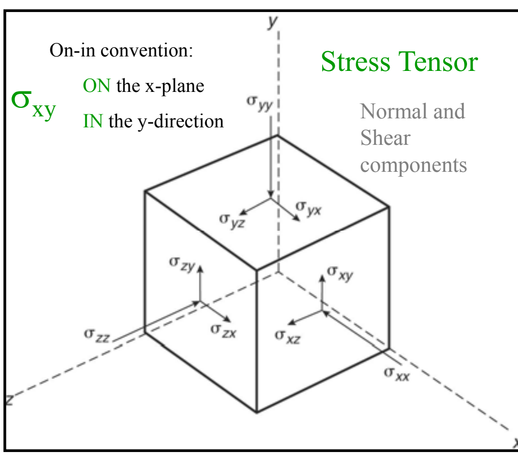
•Pressure – in fluids
•Stress – in solid bodies

Stress Tensor

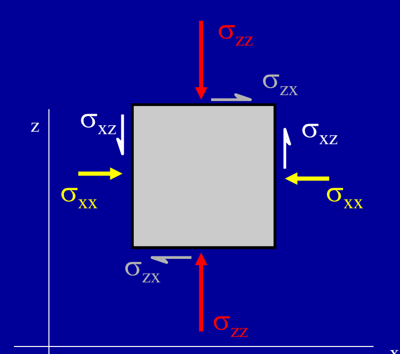
On-in convention:

σ_{xy} ON the x-plane, IN the y-direction

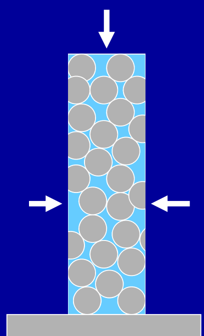
Normal and Shear components



2D Stress Tensor



Lithostatic stress/ hydrostatic stress



- Lithostatic stress
- Tectonic stress
- Fluid Pressure
  - -Hydrostatic
  - -Hydrodynamic

Lithostatic Stress

- Due to load of overburden
- Magnitude of stress components is the same in all directions

$$\sigma_{Lith} = \rho . g . z$$

gravity (g), depth (z), density (ρ)

Lithostatic Stress Gradient

$\sigma_{Lith} = \rho.g.z$

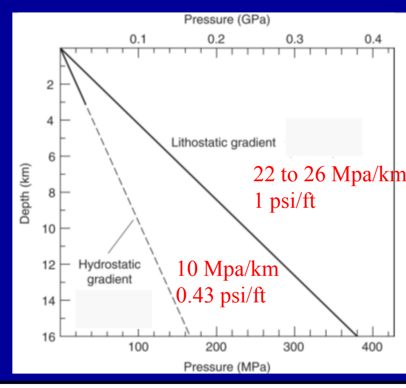
Rock density= 2000 to 3000 kg/ m^3

σ_{Lith} = 2500 kg/ m^3 x 9.8 m/ s^2 x 1000 m

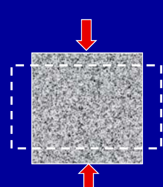
≈ 25 MPa/km

≈ 1 psi/ft

Pressure/stress gradients



What about horizontal stress?



Rocks are elastic solids

Horizontal stress depends on rock compressibility

Poisson's Ratio $\upsilon = | -e_{yy}/e_{xx} |$

υ = 0.5 incompressible material (no volume loss)

Rocks υ = 0.1 to 0.3

Horizontal Stress

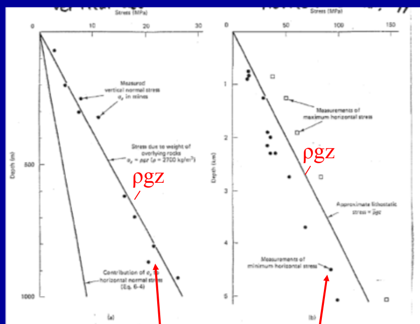
$\sigma_{Hor} = [\upsilon / (1 - \upsilon)]\ \rho.g.z$

If υ= 0.5, $\sigma_{Hor} = \rho.g.z$

If υ= 0.25, $\sigma_{Hor} = 0.33\ \rho.g.z$

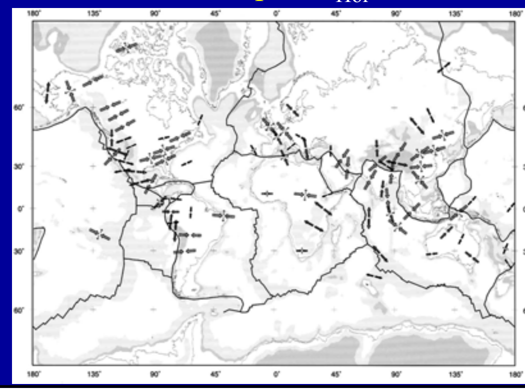
Horizontal stress is about 1/3 of vertical if rocks are lithified

Comparison of vertical and horizontal stresses



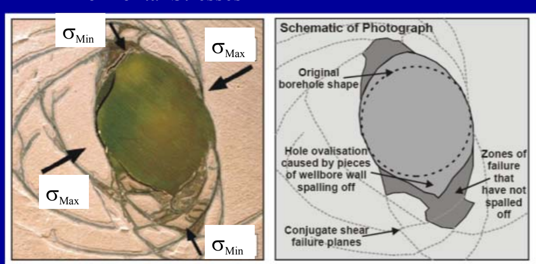
Suppe, 1985 Vertical Min horizontal

World Stress Map – σ_{Hor} direction



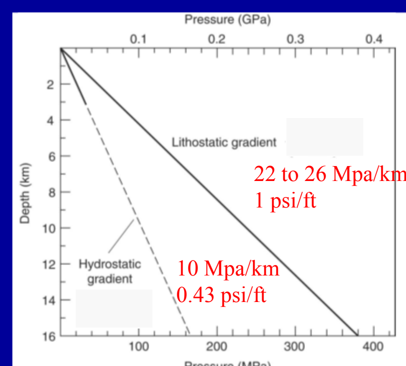
Borehole Wall Breakouts and Stress

Horizontal Stresses



Caliper log measures the shape of the borehole

Pressure/stress gradients



Overpressure =

more than hydrostatic

Spindletop, 1901

Deepwater Horizon, 2010

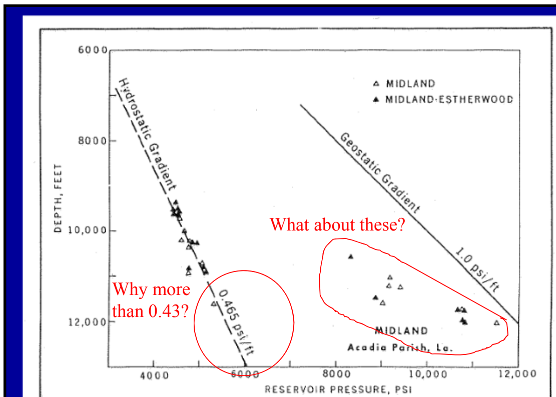
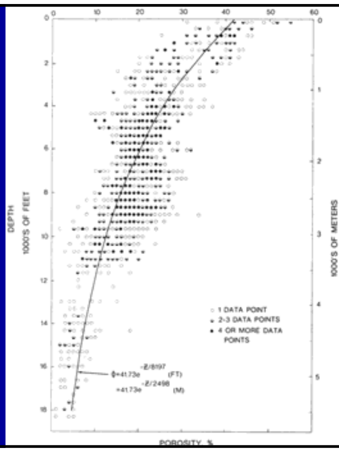


Fig. 12–28 Reservoir pressure vs depth, Midland field, Louisiana

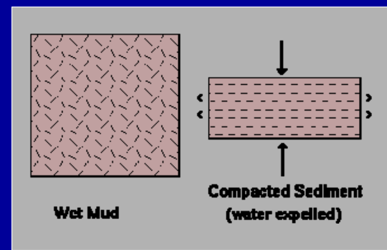


Shale Porosity vs. Depth Curve

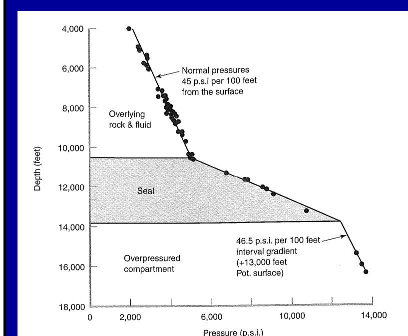
Shale compacts as water is expelled

Schmoker and Halley, 1982

Shale Compaction



Over Pressure Zone



Pressure seal inferred to exist in region of high fluid pressure gradient

Fluid pressure as a function of depth, Cook Inlet Alaska - Hunt, 1990

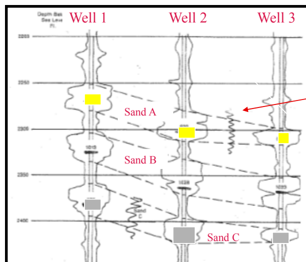


Fig. 12–15a Hypothetical cross-section showing 3 sands which correlate b electric logs. Pressure measurements reveal permeability barriers between th wells.

Pressure barrier

Reservoir Compartments

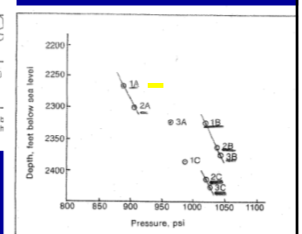
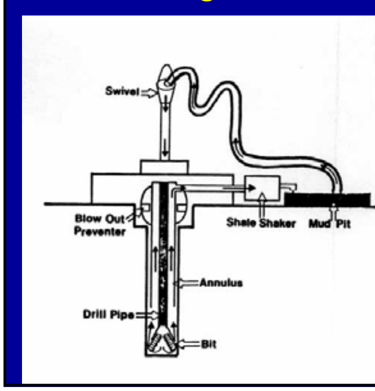


Fig. 12–15b Pressure-depth plot of wells in Fig. 12–15a. Sand A in well 3 has to high a pressure, indicating a barrier between wells 2 and 3. Sand C in well 1 ha too low a pressure in well 1, indicating a barrier in this sand between wells 1 and 2

Characteristics of Overpressure Zones

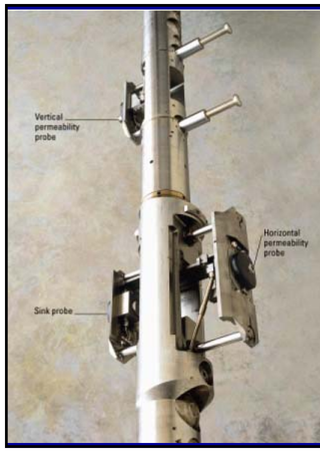
- Under-compacted shale
- Low density, low sonic velocity
- Rapid Drilling Rate
- Low Thermal Conductivy, high T
- Low Salinity

Controlling Reservoir Pressure



- Drilling Mud
- Casing
- Blow-out preventers

Blow Out Preventers



How to measure formation pressure

Formation Tester
Schlumberger

How to measure reservoir pressure?
Drill Stem Test

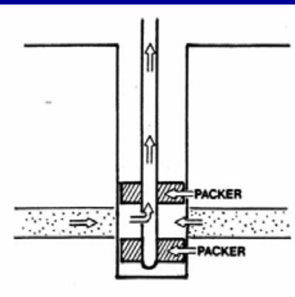
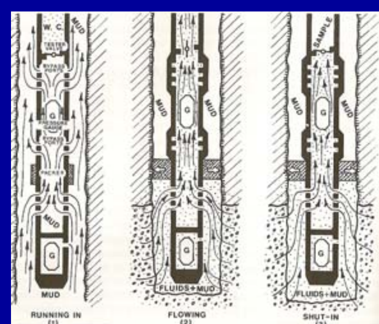


Figure 18-2 A drill stem test.

Drill Stem Test (DST)



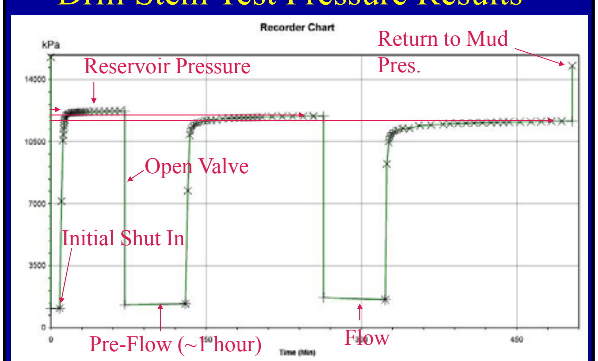
2. Initial Flow Period (IFP) removes effect of mud filtrate "supercharge"

3. Initial Shut-in is used to determine a reservoir Pressure (ISP)

Final Flow Period (FFP) is used to collect a fluid sample and create a pressure disturbance beyond any damaged zone.

Final Shut-in is used to test permeability, production rate and well damage

Drill Stem Test Pressure Results



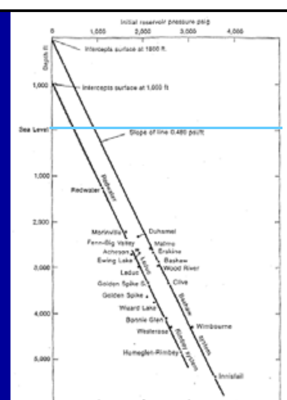
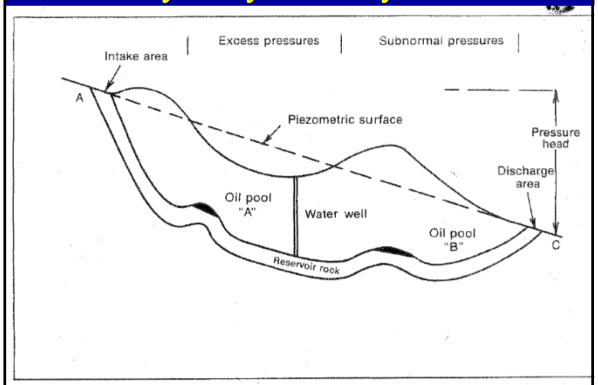


Fig. 12-4 Plot of initial reservoir pressures vs. depth of Leduc oil pools (Alberta)

Initial Reservoir Pressure
Leduc Fields, Alberta (Canada)

Leduc #1 Gas flare

Hydrodynamic System



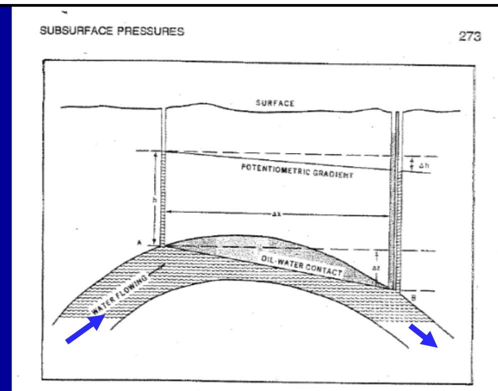
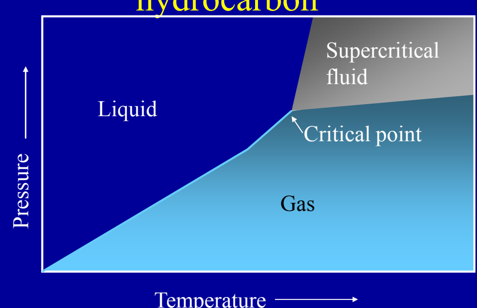


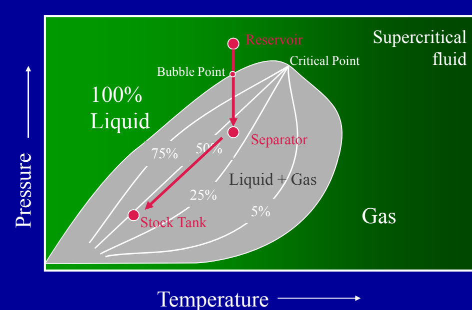
Fig. 12–20 Diagram showing why a flow results in a tilting of the oil-water contact. *(From Hubbert)*

Phase Behavior for a single hydrocarbon

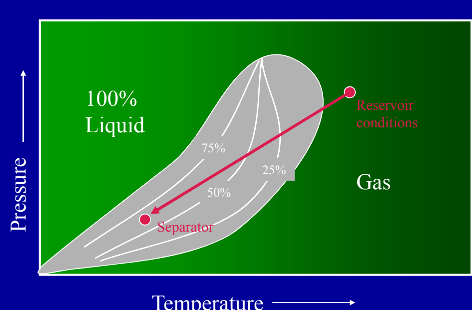


Supercritical: density like a fluid, viscosity like a gas

Phase Behavior of Gas-Oil Mix



Phase Behavior of Wet Gas or Condensate



Summary

- σ= ρ.g.z
- Hydrostatic gradient = 0.43 psi/ft or 1 Mpa/km
- Lithostatic gradient= 1 psi/ft or 25 MPa/km
- Ovepressure forms when water cannot escape
- Pressure gradient defines reservoir compartments
- Artesian aquifers can produce anomalous P
- Methods to control P during drilling
- Hydrodynamic reservoirs lead to tilted oil-water contacts
- Physical state of hydrocarbons depends on P-T regime
- Bringing oil to the surface cools and depressurizes it