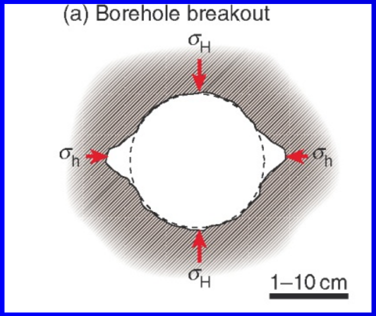
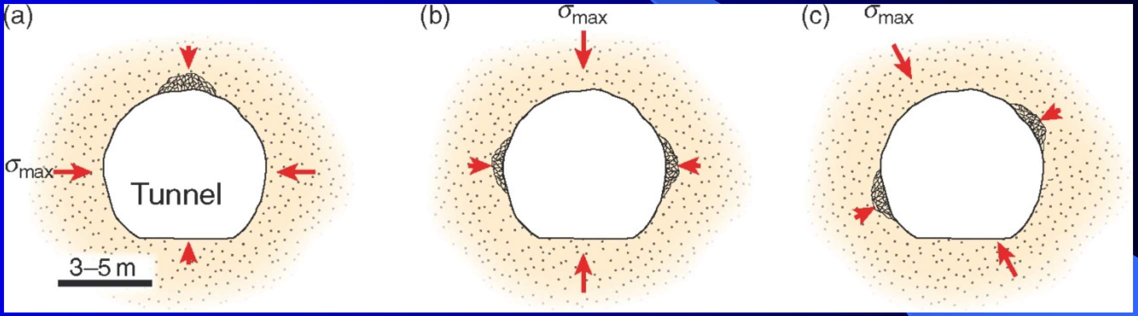
Stress in the Lithosphere

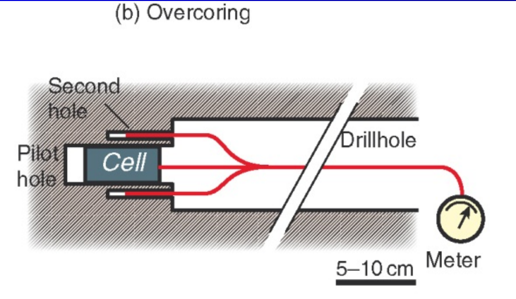
Stress Measurements

1) Breakouts – boreholes and tunnels. Breakout is parallel to minimum stress direction.

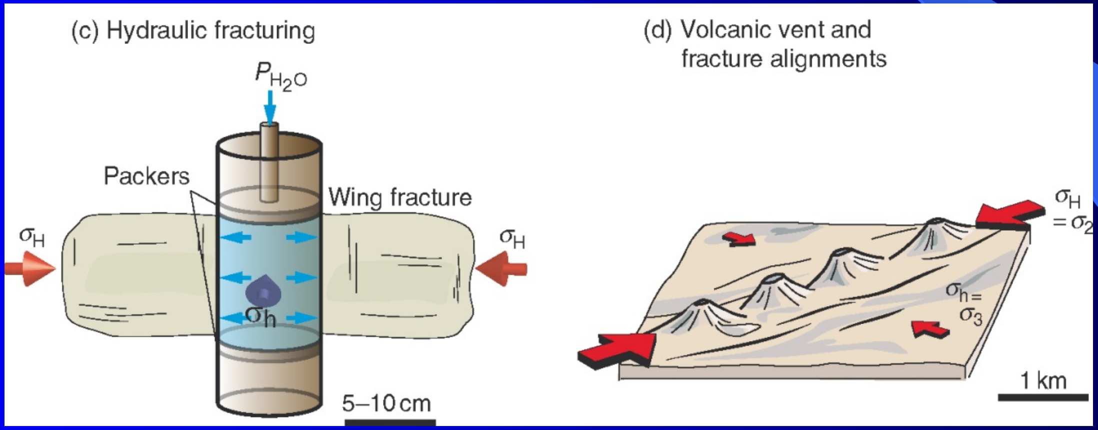




2) Overcoring – the second hole releases the stress in the core allowing the hole to expand. The change is measured using a stress meter or strain cell that is placed in the pilot hole.

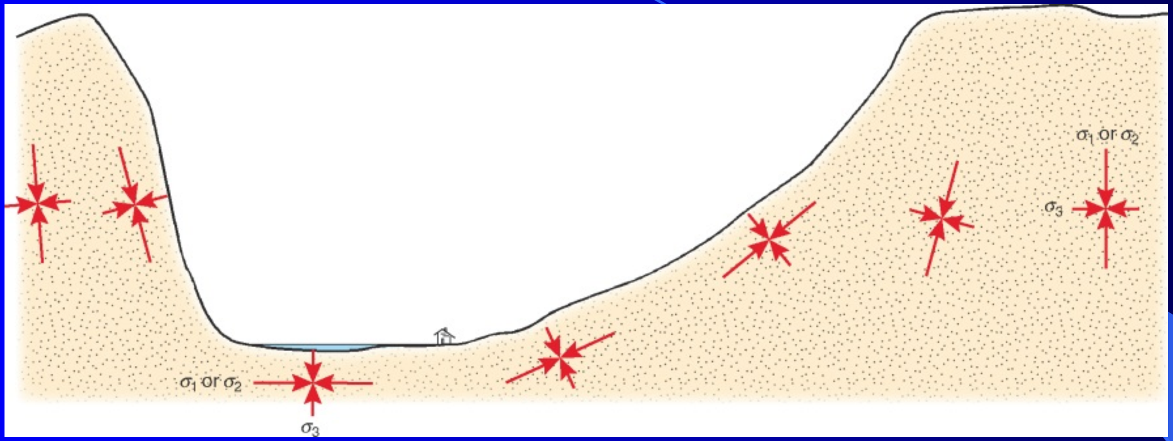


3) Hydraulic fracturing – increase fluid pressure until the rock fractures. The fracture occurs in the direction of minimum stress. The pressure needed to keep the fracture open equals σ_h. Given the tensile strength of the rock it is possible to calculate σ_H. In the simplest case, the vertical stress is the principal stress and is equal to the hydrostatic pressure = ρgz.

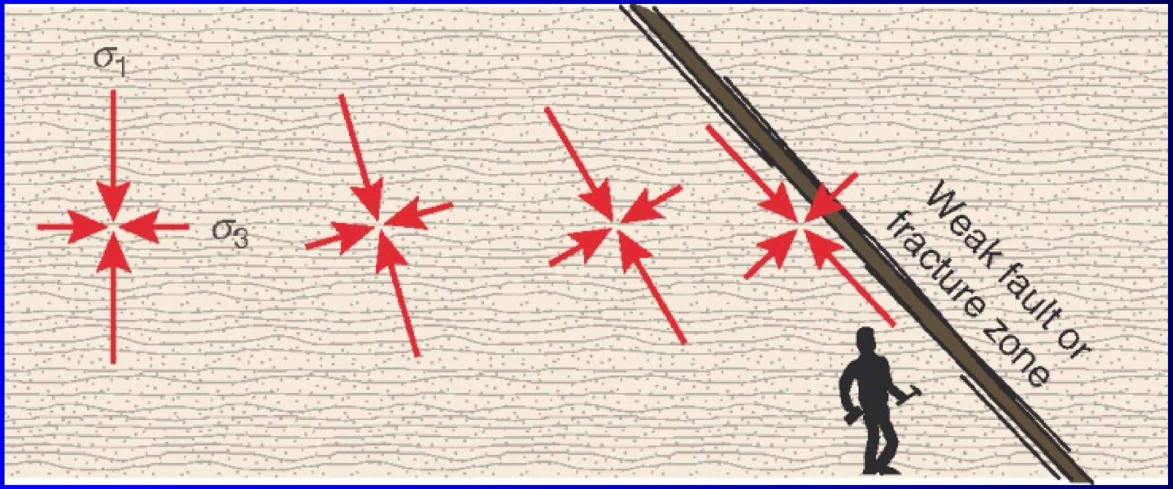


4) Geologic structures – orientation of recent fault scarps, fold traces, tensile fractures, and volcanic vent alignments.

One of the principal stresses will always be perpendicular to a free surface. This free surface can be the surface of the earth, tunnels, rock chambers, etc.



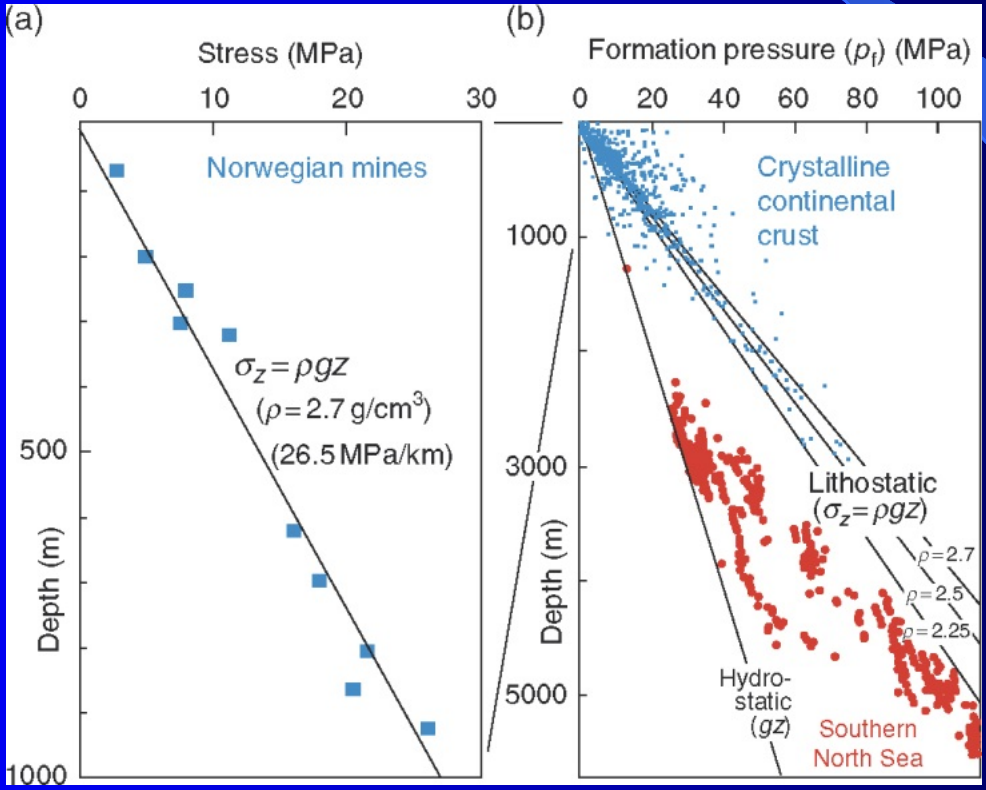
Fracture zones can also act as free surfaces



Reference States of Stress

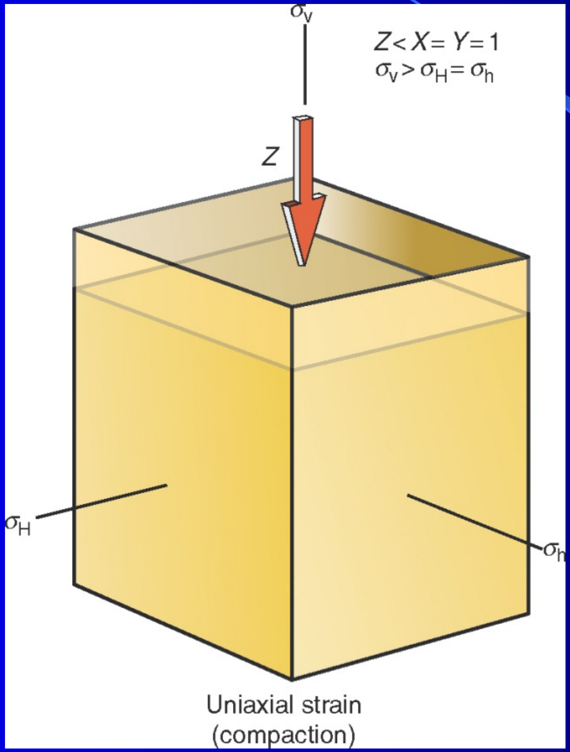
1) Reference states of stress define idealized states of stress in the curst as if the crust were a static planet with no tectonic processes.

2) The Lithostatic reference state is an isotropic state of stress where the vertical and horizontal stresses are equal.



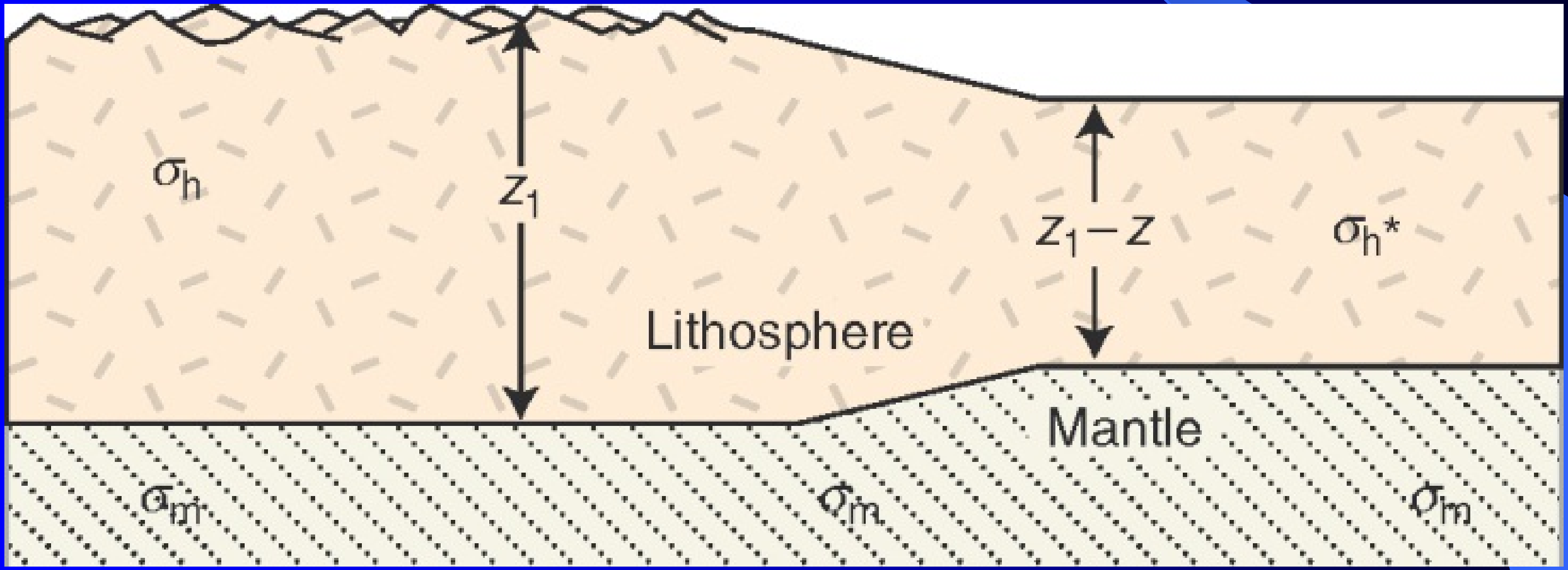
Hydrostatic versus lithostatic pressure and formation overpressure.

3) The uniaxial-strain reference state predicts that the vertical stress is considerably larger than the horizontal stress. All the strain is in the vertical direction, no strain in the horizontal direction.



$$\sigma_H = \frac{\nu}{1-\nu}\sigma_v = \frac{\nu}{1-\nu}\rho g z$$

4) The constant-horizontal-stress reference state is based on the assumption that the average stress in the lithosphere is the same to the depth of isostatic compensation (Z_1). Below this depth the mantle has no shear strength over geologic time and the mantle behaves like a fluid.



Thermal Effect on Horizontal Stress

$$\Delta\sigma_h^T = \frac{E\alpha_T(\Delta T)}{1-\nu}$$

Stress Variation During Burial and Uplift

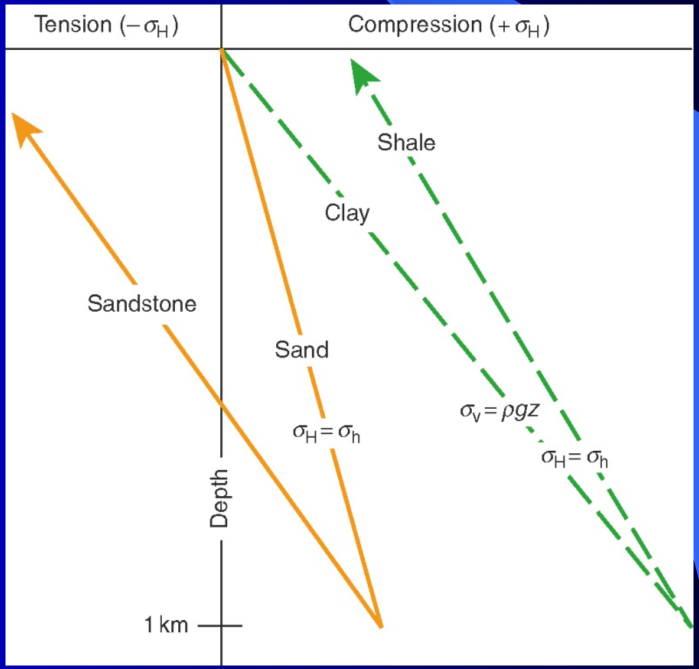
$$\sigma_H = \sigma_h = \frac{\nu}{1-\nu}\Delta\sigma_v + \frac{E}{1-\nu}\alpha_T\Delta T$$

E = Young's modulus

ν = Poisson's ratio

α_T = linear thermal expansion coefficient

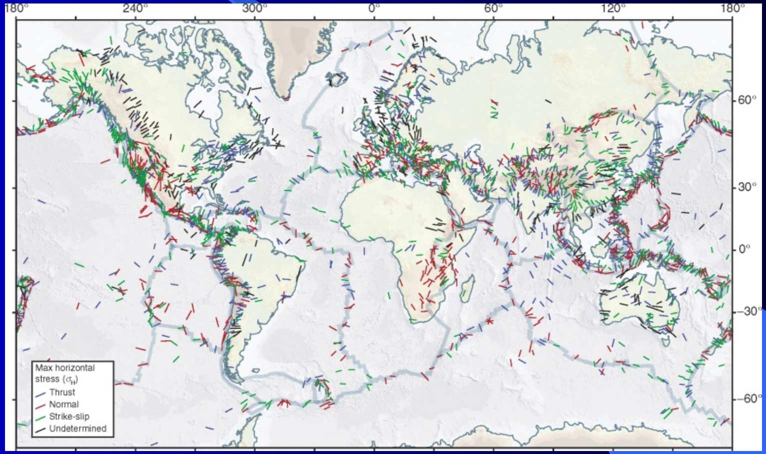
$\Delta\sigma_v$ = change in vertical stress

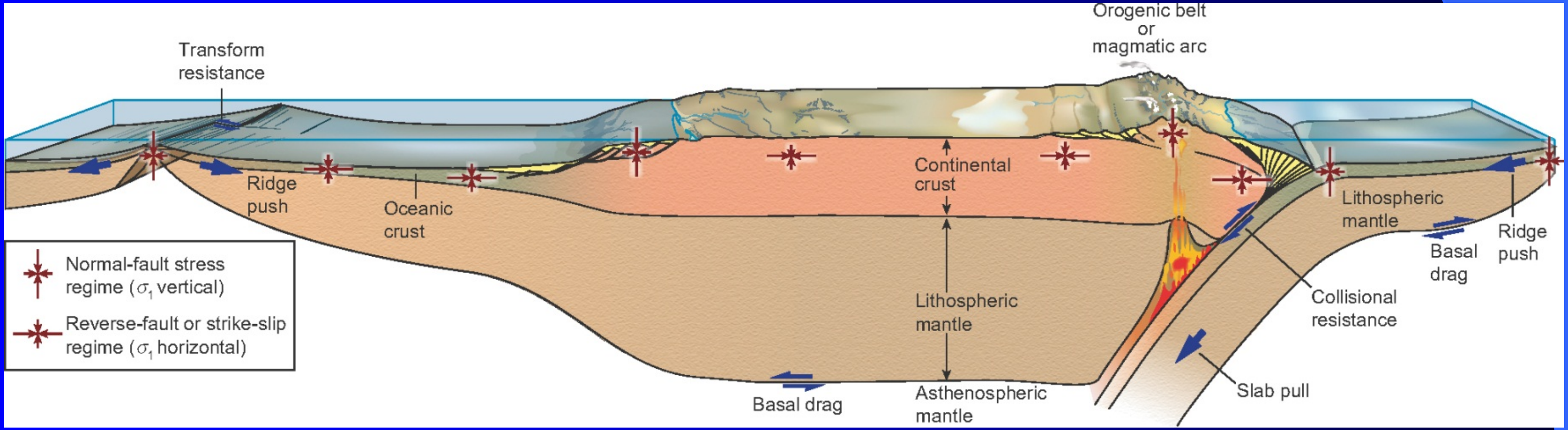


Tectonic stresses are those parts of the local stress field that deviate from the reference state of stress as a consequence of tectonic processes.

Current tectonic stress = Total stress – (reference state of stress + non-tectonic residual stress + thermal stress + terrestrial stress [related to seasonal and daily temperature changes, earth tides, etc.])

Global stress patterns – plate tectonic processes are responsible for a global stress pattern that is locally modified by gravity-controlled second-order sources of stress.





Differential stress at any given point in the Earth is limited by the strength of the rock itself. Any attempt to increase the differential stress above the ultimate rock strength will lead to deformation.

The strength of various rock types increases with confining pressure (burial depth). The absolute strength depends on lithology (mineralogy).

When the differential stress exceeds the strength of the rock, the rock will deform.