

12.113 Structural Geology
Part 2: Brittle deformation and faulting

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Chapter 1

Brittle material behaviour

1.1 Reading assignment

Twiss and Moore's chapter nine is essential reading for this stuff, and parts of chapter ten are definitely relevant.

1.2 Failure criteria

1.2.1 Tensile stress

$$\sigma_1 = \sigma_2 \gg \sigma_3$$

And σ_3 is negative. Open tension fractures containing σ_1 and σ_2 and perpendicular to σ_3 .

Draw a Mohr circle for this situation:

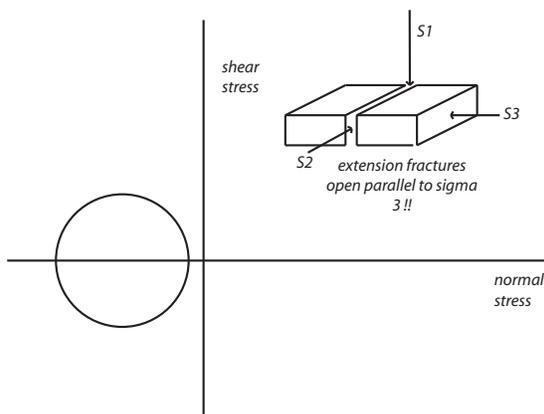


Figure 1.1: Mohr construction for tensile stresses

1.2.2 Shear fractures in non-cohesive material

For instance, loose sand. Byerlee in the 50s conducted various experiments looking at the strength of these sorts of materials, where strength is understood as the amount of shear stress necessary to initiate motion, given a certain amount of normal stress. If you plot shear stress necessary to initiate motion against normal stress, you get a line which makes an angle ϕ with the normal stress axis. The equation describing this relationship is **Byerlee's law**, and written as

$$\tau_c = \sigma_N \tan \phi = \mu \sigma_N$$

where ϕ is called the **angle on internal friction** and μ is the coefficient of friction. We can create a Mohr construction that illustrates how this equation provides a physical law for predicting when failure will occur in a material:

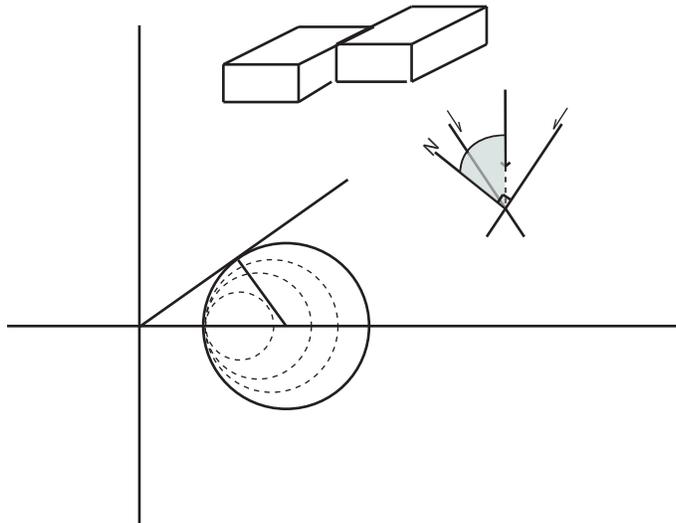


Figure 1.2: Mohr construction for shear failure according to Byerlee's law (no cohesion). As an exercise, label the figure with τ , σ_N , 2α , α , σ_1 , σ_3 , and ϕ . Also, use this diagram to derive the relationship $\alpha = 45 + \phi/2$

1.3 Cohesive material

Given the above failure criterion, in the absence of a confining stress, the shear stress for failure will be zero. But materials have strength even in the absence of confining stress – this is known as the **cohesion**. A modified failure criterion incorporating this is the **Mohr-Coulomb** failure criterion:

$$\tau = C + \sigma_N \tan \phi$$

Draw the Mohr circle construction for this.

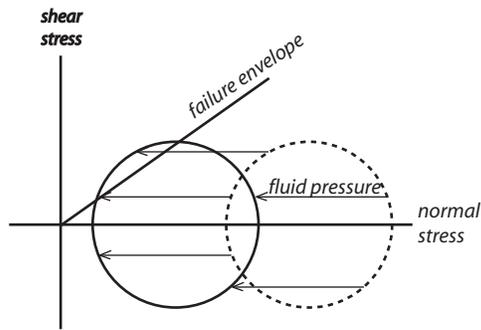


Figure 1.3:

1.4 Effect of pore fluid pressures

The effect of a pressurized fluid on a fault plane is to decrease the normal stress by that pressure. In this case, the Mohr-Coulomb failure criterion becomes

$$\tau = C + \sigma_{Neff} \tan \phi = C + (\sigma_N - P_f) \tan \phi$$

where P_f is the fluid pressure. On a Mohr diagram, the effect of fluid pressure is to shift the Mohr circle to the left of the diagram. As fluid pressures go up, the possibility that the Mohr circle intersects the failure envelope is increased.

1.5 Review questions

Lab 1 on stress, particularly the orientation of principal stresses in relation to fault types and tectonic environments. Lab 5 on faults, particularly the problems on joints and Downie's slide.

What does a generalized failure envelope taking into account both tensile and shear failure look like?

In general, what is the effect of higher mean stress (pressure)? What implications does this have for the brittle failure of materials at greater and greater depths?

Chapter 2

Faults – General

2.1 Reading assignment

Chapter 4 is essential reading. There's a lot of terminology: I suggest you make a glossary for yourself, adding little cartoons helps, too.

For the discussion of stress distributions, see section 10.9, pages 202 – 205.

2.2 Terminology

For the following terms, write yourself a definition, or, better, draw a cartoon or find a representative figure.

slip vs. separation

slickensides, slickenlines

fault scarps, fault-line scarps

breccia, gouge.

conjugate faults

Drag folds, shift.

Dip-slip faults: **reverse (thrust), normal**. Strike-slip faults: **right-lateral, left-lateral**.

2.3 Stress distributions, faulting and tectonic setting

Rock mechanics and Anderson's theory of faulting give us a first order picture of how the types and orientations of faults are related to the orientations of principal stresses. In particular, this was the subject of an exercise in the first lab on stress, and in the lab about faults. The idea follows from the results of rock deformation experiments, where it has been observed that shear fractures occur as conjugate sets such that the greatest principal stress bisects the conjugate shear fractures. Since the Earth's surface must be a principal plane of stress (no shear stresses are transmitted across the Earth's surface), Anderson fault theory predicts that normal faults occur where the greatest principal stress is vertical, thrust faults occur where the least principal stress is vertical and strike-slip faults occur where both greatest and least principal stresses are horizontal. Since the greatest principal stress is usually at an acute angle to the shear fractures, this also predicts that normal faults ought to be steep, and thrusts are shallow. However, there definitely are steep thrust faults (reverse faults) and very low angle normal faults. Part of this results from the inherent uncertainty and imprecision of the Mohr-Coulomb model of fault formation, but part of it has to do with the fact that stress orientations ought to change with depth.

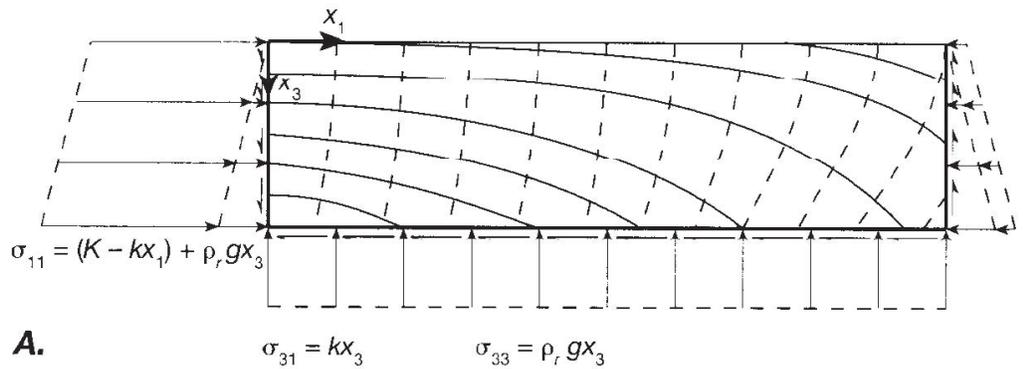


Figure 2.1: From Twiss and Moore, see textbook for discussion

Consider a "free body" diagram where a compressive tectonic stress is added to the standard state of stress (pressure due to rock thickness increases linearly with depth). If this stress is sufficiently high, you will get faulting, but stress trajectories are straight lines. More importantly, if you consider the addition of shear stresses at the base, much more interesting stress orientations result. Horizontal shear stresses have to be balanced by vertical shear stresses and all shear stresses must vanish at the surface. The result is that the free body diagram shows curved stress trajectories and a much wider variety of predicted fault orientations. As an exercise, take the diagrams of stress trajectories and draw on the expected orientations of faults.

2.4 Slides

For each of the slides, take a pen and draw on the fault or faults, and interpret them: what kind of fault, active or not, what kind of structure. Can you tell slip or just separation? Write a caption for each figure.



Figure 2.2:



Figure 2.3:



Figure 2.4:



Figure 2.5: The San Andreas fault



Figure 2.6: Faulted alluvial material.



Figure 2.7: Sag-pond on active fault.



Figure 2.8: Note that the fault surface is not quite planar. The cylindricity of the fault surface is an important indicator of the kinematics of motion



Figure 2.9: Slickensides



Figure 2.10: Fault gouge



Figure 2.11: Huge thickness of gouge at Tucki mountain, Death Valley, CA.



Figure 2.12: Mylonite. Fault gouge, fracture and fault breccia are all expressions of brittle failure. Mylonites are produced by ductile deformation mechanisms and are the deep, hot equivalent of brittle faults.

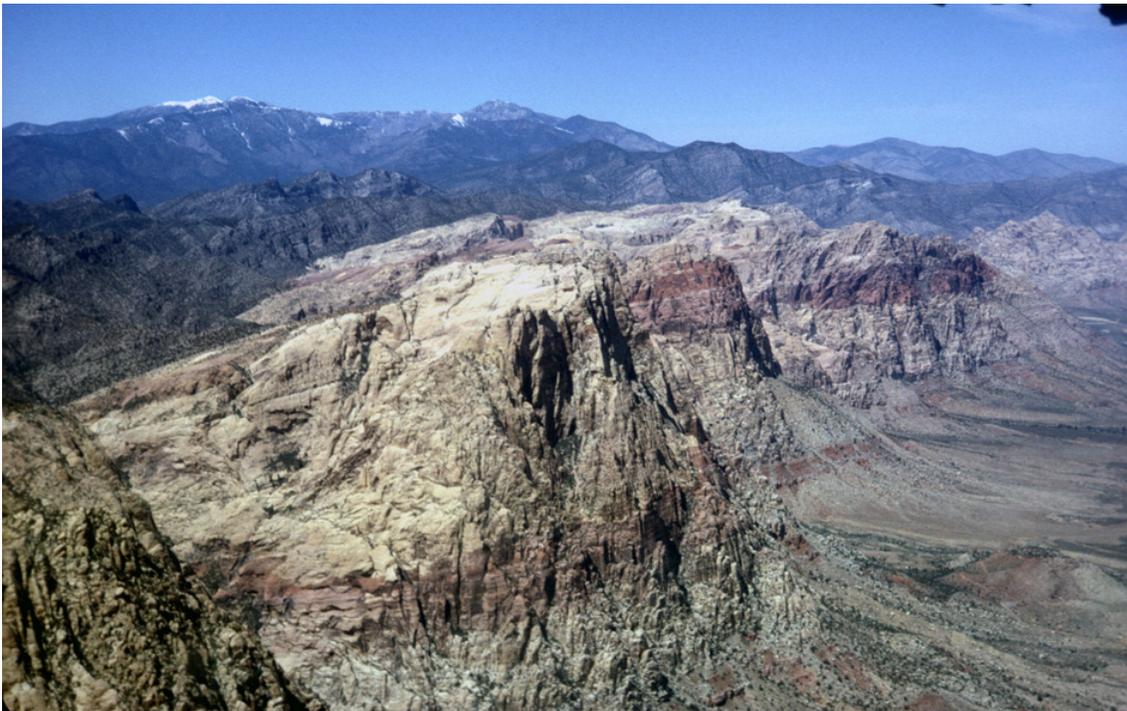


Figure 2.13: The Keystone fault



Figure 2.14: Another view of the Keystone fault. Red rocks are the Jurassic Aztec sandstone. Dark grey rocks are the Cambrian Bonanza King dolostone. What is the nature of the contact? What is the direction of transport?