GLG310 Structural Geology, Fall 2013

Professor Ramon Arrowsmith

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Tuesdays and Thursdays, 10:30-11:45 AM, SK 314 (Lecture)
Mondays OR Thursdays 1:30-4:30 pm, PSB 469 or in the field (Lab)

Mechanics of faulting

\[ \sigma = \frac{1}{3}(\sigma_1 + \sigma_3) + \frac{\sigma_1 - \sigma_3}{3} \cos 2\theta, \]

\[ \tau = \frac{1}{3}(\sigma_1 - \sigma_3) \sin 2\theta, \]

Mohr's Circle and equations for stress

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Mechanics of faulting

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http://www.iris.edu/hq/programs/education_and_outreach/animations/1

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Mechanics of faulting
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**Figure 6.69** Plot of Byerlee's law of sliding friction, which is based on hundreds of sliding friction experiments on a wide variety of rock types. (From Byerlee, J. D., Friction of rocks, 1978, Pure and Applied Geophysics, v. 116, Birkhauser Verlag Ag, Basel, Switzerland.)
Frictional strength

Coulomb Law of Failure

Coulomb equation

\[ \sigma_c = \sigma_0 + \tan \phi \sigma_n \]

Where

\( \sigma_c \) = critical shear stress required for faulting (shear strength)
\( \sigma_0 \) = cohesive strength
\( \tan \phi \) = coefficient of internal friction = \( \mu \)

And, 1 bar = 100,000 Pa
Optimally oriented faults

Figure 6.67 Mohr diagram portrayal of the dynamic conditions of the sandbox experiment. (A) Differential stress conditions leading to normal faulting in the left-hand compartment. (B) Differential stress conditions leading to thrust faulting in the right-hand compartment.
Optimally oriented faults

For triangle ABC:

\[ \alpha + \beta + \gamma = 180 \]

\[ \alpha = 90 - \phi \]

\[ \beta = 90 - \phi \]

\[ \gamma = 180 - (90 - \phi) - (90 - \phi) \]

\[ \gamma = 2\phi \]

\[ \phi = \frac{180}{2} \]

\[ \phi = 90 \]

\[ \gamma = 180 - 90 - 90 = 0 \]

\[ \gamma = 0 \]

\[ \phi = 90 - \gamma = 90 - 0 = 90 \]

\[ \theta = \arctan(0.6) \]

\[ \theta = 31^\circ \]

\[ \alpha = \theta + \gamma + \phi \]

\[ \alpha = 31 + 0 + 90 = 121 \]

\[ \phi = 90 - \theta \]

\[ \phi = 90 - 31 = 59 \]

\[ \theta = 60.5^\circ \]

So what is optimum dip?

Reverse fault

Normal fault
Andersonian Faulting Theory

Figure 6.74 Schematic representation of (A) thrust faults, (B) normal faults, and (C) strike-slip faults at or near the surface of the earth. These are the likely orientations since each of the three principal stress directions at or near the surface of the Earth is either horizontal or vertical, and since the angle of internal friction for rocks is almost always $\sim 30^\circ$.
So, what will it take to make a fault fail near the lake?
So, what will it take to make a fault fail near the lake?

Assuming that there was an optimally oriented fault

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So, what will it take to make a fault fail near the lake?

Assuming that there was an optimally oriented fault
So, what will it take to make a fault fail near the lake?

If you had to fail one of the existing faults
The mechanical paradox of overthrust faulting—Hubbert and Rubey

Figure 6.107  The famous beer can experiment. (Artwork by D. A. Fischer.)

Figure 6.108  Wedge-shape nature of thrust belts, as illustrated by the Canadian Rockies. [From D. M. Davis, J. Suppe, and F. A. Dahlen, Journal of Geophysical Research, v. 88, figure 1a, p. 1154, copyright © 1983 by American Geophysical Union.]
Increase pore pressure to 25 MPa:

Figure Locations of seismic events caused by or likely related to human activities within the coterminous United States and portions of Canada as documented in the technical literature.

*Induced seismicity is largely caused by increase pore pressure*
Rocky Mountain Arsenal correlation between fluid injection and earthquakes

Figure: Histograms showing relation between volume of waste injected into the Rocky Mountain Arsenal well and earthquake frequency.

Add Quakes to Rumblings Over Gas Rush

BY HENRY FOUNTAIN
Published: December 12, 2011

YOUNGSTOWN, Ohio — Until this year, this Rust Belt city and surrounding Mahoning County had been about as dead, seismically, as a place can be, without even a hint of an earthquake since Scots-Irish settlers arrived in the 18th century.
But on March 17, two minor quakes briefly shook the city. And in the following eight months there have been seven more — like the first two, too weak to cause damage or even be felt by many people, but strong enough to rattle some nerves.

“It felt like someone was kicking in the front door. It scared the stuffing out of me,” said Steve Moritz, a cook who lives on the city’s west side, describing the seventh quake, which occurred in late September. It was the strongest one, with a magnitude of 2.7.

Nine quakes in eight months in a seismically inactive area is unusual. But Ohio seismologists found another surprise when they plotted the quakes’ epicenters: most coincided with the location of a 9,000-foot well in an industrial lot along the Mahoning River, just down the hill from Mr. Moritz’s neighborhood and two miles from downtown Youngstown.

At the well, a local company has been disposing of brine and other liquids from natural gas wells across the border in Pennsylvania — millions of gallons of waste from the process called hydraulic fracturing that is used to unlock the gas from shale rock.