GEOL 3700 Structure and Tectonics
Laboratory Exercise 7
Interpretation and Analysis of Stress from Mapped Structures

Goals:
The primary goal of this lab exercise is to learn to interpret stress and strain from mapped geologic structures. This exercise also provides the opportunity to improve your skills reading geologic maps, analyzing orientation data with a stereonet, and relating rock mechanics experiments to real world geologic structures.

Background Information:
This exercise deals with the structural geology and tectonics of south-central Alaska. The region has been the site of plate convergence since Mesozoic time. Today and in the past convergence has been oblique – rather than perpendicular – to the plate boundary, which has resulted in the formation of right-lateral strike-slip faults inland from the boundary. During Mesozoic and Cenozoic time, slivers of crust apparently have been transported along the North American continental margin from the latitude of Baja California to their present location in Alaska along these margin-parallel strike-slip faults. The magnitude 7.9 earthquake on the Denali fault last year was a dramatic manifestation of the inland strike-slip faulting. Historically, a major question in structural geology and tectonics has been why oblique convergence results in the formation of strike-slip faults and virtually perfectly orthogonal subduction rather than the subducting plate simply subducting at an oblique angle to the plate boundary (Figure A).

![Figure A. Three examples of present-day oblique subduction that has resulted in the formation of strike-slip faults.](image)

Figure A. Three examples of present-day oblique subduction that has resulted in the formation of strike-slip faults. In each case, the oblique convergence between the two plates is divided into nearly perfectly orthogonal subduction and strike-slip faulting. The sliver of crust between the strike-slip fault(s) and the trench is transported along the plate margin.
Your task today is to address this question by studying another strike-slip fault, and structures along it, that may have formed in response to the oblique convergence – the Castle Mountain fault (CMF). The Castle Mountain fault lies in the southern Talkeetna Mountains to the northeast of Anchorage. Tens or more kilometers of right-lateral displacement have accumulated on it since early Tertiary time. Two recent earthquakes and scarps in glacial debris reveal that it is active and seismogenic – an added reason to study this fault. Structures along the fault are nicely exposed at a place called Wishbone Hill, where coal was extracted in the past.

The movement of the Pacific plate (and its subducted, long gone predecessors) relative to North America is towards 330 to 340°. That is nearly orthogonal to the CMF, yet it clearly has and is slipping right-laterally. The Coulomb – Navier failure criterion and Byerlee’s Law tell us that faults should form at about 30° to \( \sigma_1 \). How then can the right-lateral strike-slip motion occur on the CMF, which lies nearly orthogonal to the plate motion direction? There are two hypotheses to explain this observation. One is that \( \sigma_1 \) refracts (bends) from the plate motion direction near the fault, and the \( \sigma_1 \) makes an angle of about 30° to the CMF near to the fault. Alternatively, the CMF may slip in response to \( \sigma_1 \) nearly parallel to the plate motion direction, which would require that the CMF is a very weak feature in the crust (Figure B).

Figure B. Possible paleo-stress fields to explain right-lateral slip on CMF in response to Pacific - North American plate convergence. A, \( \sigma_1 \) is controlled regionally by the direction of plate convergence and refracts to drive slip on the CMF in accord with Byerlee’s Law. B, \( \sigma_1 \) parallels the plate convergence direction regionally and on the CMF, and the CMF slips right-laterally at very low shear stress in response to this \( \sigma_1 \) orientation.
**Tasks:**
Your task today is to test the two hypotheses for the existence of the Castle Mountain fault. You can do this by inferring from mapped geologic structures the orientations of the principal stress and strain directions near the fault. Below are a series of steps that you can follow to help you with your analysis.

1. Look over figures 1 and 2 to get a big picture view of the geologic setting of south-central Alaska.
2. Look at figure 3, which is a geologic map of the Wishbone Hill District. The area was a coal mining district, which is of great benefit to us. Open-pit style mining left some fantastic rock exposures, and subsurface mining provided information on fault displacements. There are four types of structures from which you can infer stress and strain. Note that the structures deform rocks of Paleocene through Eocene age, but have little or no effect on the Oligocene Tsadaka formation. These relations show that the structures formed primarily in Eocene time. Consequently, it is likely that they all formed in response to the same stress state.
3. Moose Creek Thrust. The moose creek thrust dips about 45° to the southeast, and lineations on the fault surface show that movement on it was pure dip-slip. Measure the strike of the fault from the map, and plot the fault on a stereonet as a great circle and its pole. If $\sigma_1$ lies at 30° to the fault (as suggested by Coulomb-Navier/Byerlees Law behavior), what is the orientation of $\sigma_1$, $\sigma_2$ and $\sigma_3$?
4. Wishbone Hill Syncline. If the fold formed in response to $\sigma_1$ at right angles to the fold hinge, what was the orientation of $\sigma_1$?
5. Strike – slip faults. Wishbone Hill is cut by several vertical, strike – slip faults. For each of these faults, measure its strike, plot it on a stereonet and infer and plot $\sigma_1$, $\sigma_2$ and $\sigma_3$ that may have caused the faults to form. Assume Coulomb-Navier/Byerlees Law behavior for the formation of the faults. This is a reasonable assumption because the faults have relatively small displacements. Do the faults give consistent principal stress directions? Estimate an average $\sigma_1$, $\sigma_2$ and $\sigma_3$ set of directions from the faults.
6. Dikes. Two Tertiary aged, vertically dipping dikes cut the rocks of Wishbone Hill. If these dikes formed as extensional fractures, what was the orientation of $\sigma_3$ when they formed? To answer this question, measure their strikes from the map and plot their poles on the stereonet. If the dikes formed as extensional fractures, we can infer that $\sigma_1$ was in the plane of the dikes, but the dikes provide no information on its plunge. However, if $\sigma_1$ was horizontal when the dikes formed, what was its trend?
7. Combine the stress directions that you inferred from each type of structure onto one stereonet and pick an average set of principal stresses by eye. Make sure that your average principal stress directions are mutually orthogonal. Plot the 340° plate convergence direction on the same overlay.
8. Compare the $\sigma_1$ direction that you inferred from the structures on Wishbone Hill with the plate motion direction. Which hypothesis do your results support? What do your results imply for the mechanical behavior of the CMF? Does it necessarily violate Byerlee’s Law, or might unusual conditions exist in the CMF that allow it to obey Byerlee’s Law and yet have slipped in response to the stress state that you inferred?
Figure 1. Map of Cook Inlet region, showing important geographic features, oil and gas fields, large anticlines, and major faults. Oil and gas fields are labeled as follows: BC = Beaver Creek field, BR = Beluga River field, F = Falls Creek field, I = Ivan River, M = Middle Ground Shoal field, and SR = Swanson River field. Modified from Haeussler et al. (2000) and Bunds (2001).
Figure 2. Geologic map and major rock units of the Castle Mountain fault study area, with Wishbone hill marked. Also shown are the focal mechanisms of the 1984 and 1996 earthquakes on the Castle Mountain fault (Lahr et al., 1986), and the Caribou and Castle Mountain fault splays. The focal mechanisms for both events are well constrained and in both cases the fault plane is interpreted to be the plane with right-lateral slip sub-parallel to the CMF (1984, 060/70 NW; 1996, 079/85 NW). Modified from Fuchs (1980), Winkler (1992) and Bunds (2001).
Figure 3. Geologic map of the Wishbone Hill area. Note left lateral faults, synclinal axis, the Moose Creek thrust and dikes. Key to map units: Qag - alluvial and glacial deposits; Qls - landslide debris; Ti - intrusive rocks (dikes); Tt - Tsadaka formation; Tw - Wishbone formation; Tc - Chickaloon formation; Tar - Arkose Ridge formation. See figure 2 for rock descriptions. Modified from Barnes and Payne (1956), Barnes (1962) and Bunds (2001).