PROBLEM SET #X

PART A:
The geologic map on page 3 is from an area consisting of faulted Miocene sedimentary rocks. There are two major faults exposed here: the Rattlesnake fault and the Jackrabbit fault. Based on the map view pattern and field observations, it is clear that the Jackrabbit fault cuts the Rattlesnake fault. Using this map and your knowledge of fault mechanics, answer the following questions.

1) What is the orientation (strike and dip) of the Rattlesnake fault?

Basic three point problem: draw two strike lines (~N48E), measure horizontal distance between strike lines (scale = 1:2,500), and calculate dip with trig: dip = $\tan^{-1}$ (horiz distance btw. strike lines/elevation difference btw. strike lines) = ~33°; attitude = N48E, 33°SE

2) Draw a cross section from A-A' using the topographic profile provided on page 3.

3) What types of faults are the Rattlesnake fault and Jackrabbit fault?

Normal faults with SE-down displacement.

4) Based on your cross section, how much apparent displacement is there on the Rattlesnake fault? On the Jackrabbit fault?

~63 m slip on the Rattlesnake fault; ~19 m on the Jackrabbit fault.

5) Assuming that these strata were horizontal at the inception of faulting in this area, what was the initial dip of the Rattlesnake fault?

Strata in hanging wall and footwall are tilted ~27° NW, indicating that Rattlesnake fault restores to ~60° dip (=33°+27°)

6) As the Rattlesnake fault rotated to its current orientation, friction along the fault increased. The Jackrabbit fault cut through these beds at ~4 km depth after slip on the Rattlesnake fault ceased due to frictional lockup. Assuming an Andersonian stress field, what was the direction and magnitude (in MPa) of σ_1 when the Jackrabbit fault formed? (note: the average density of these strata is ~2,500 kg/m^3).

σ_1 = vertical (Andersonian theory for normal faulting); vertical stress = lithostatic stress = ρgh = (2,500 kg/m^3)(9.8 m/s^2)*(4,000 m) = 98 MPa*

7) Assuming there was no pore fluid pressure, determine the magnitude and direction of σ_3 when the Jackrabbit fault formed (via Mohr-Coloumb failure). Use the Mohr space diagram on page 4 to draw a Mohr circle that illustrates this stress state during formation of the Jackrabbit fault.

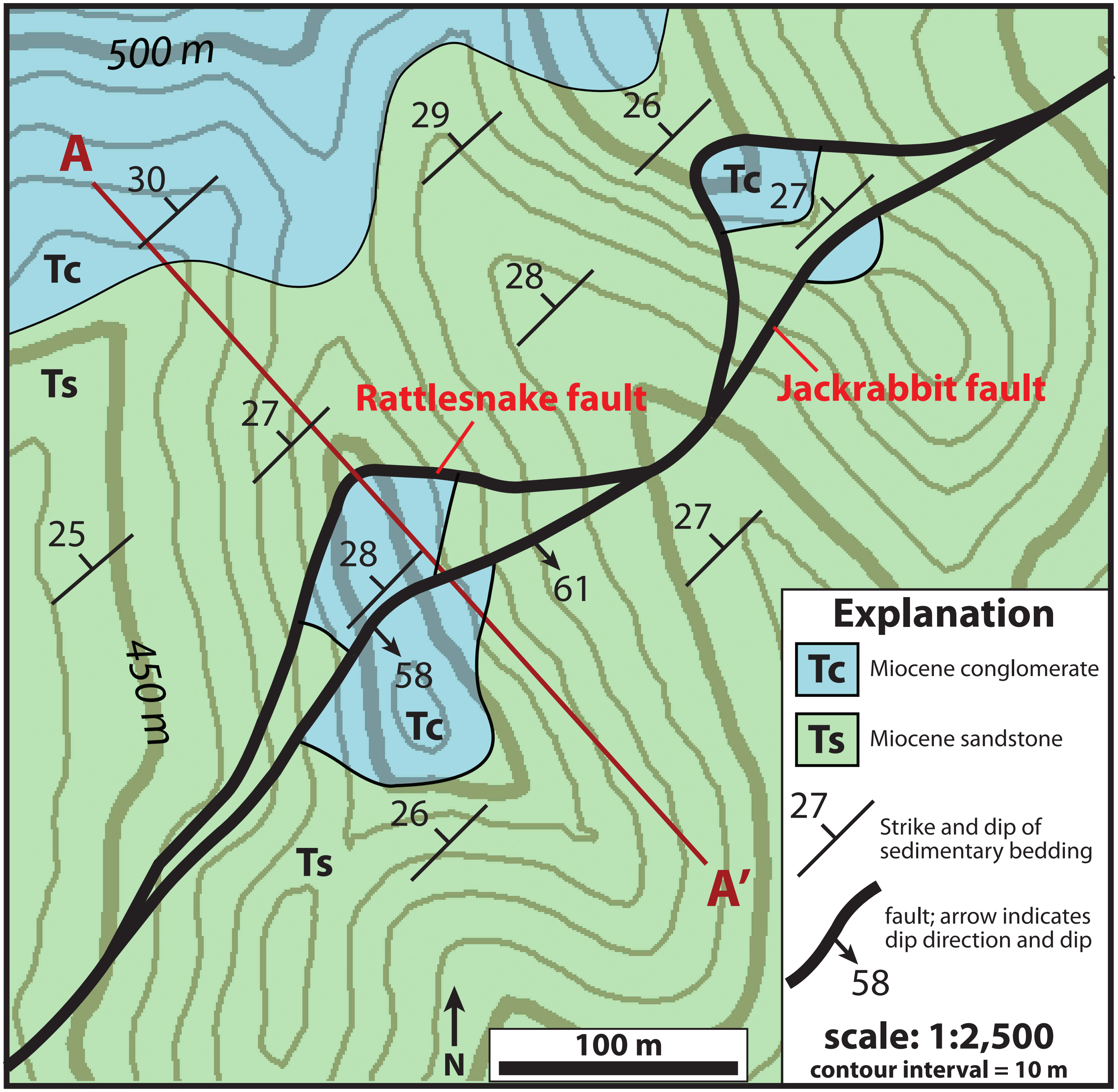
Mohr circle with σ_1 = 98 MPa will intersect Coloumb failure envelope if σ_3 = 8 MPa. σ_3 = horizontal NW-SE (N42W-S42E if fault slip is parallel to the fault dip direction)

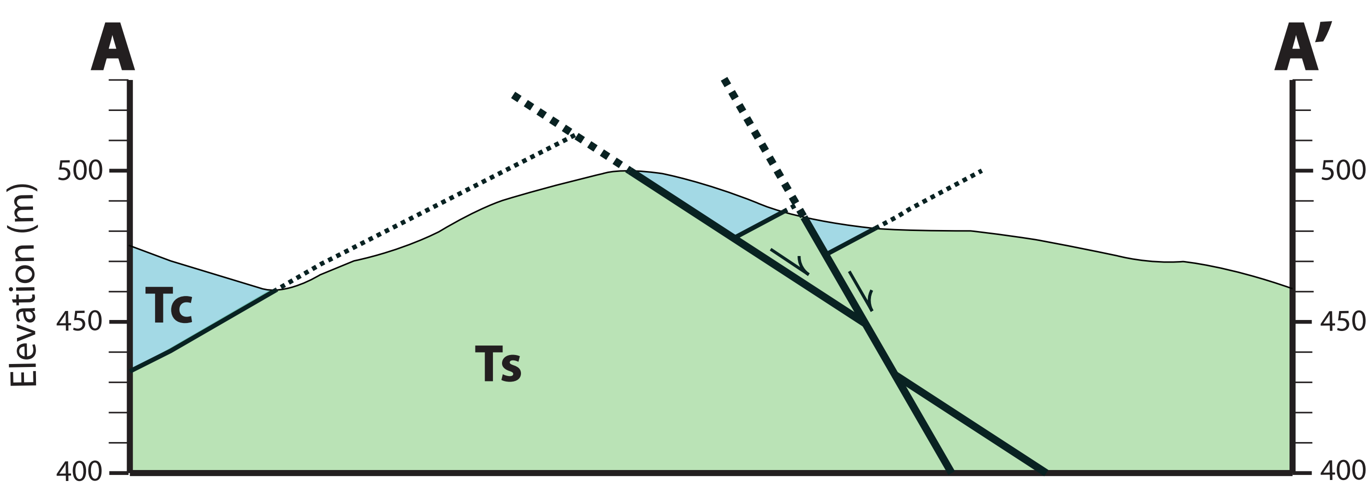
8) Now assume that pore fluid pressure was hydrostatic when the Jackrabbit fault formed. What was the magnitude of σ_3? Again, illustrate with a Mohr circle.

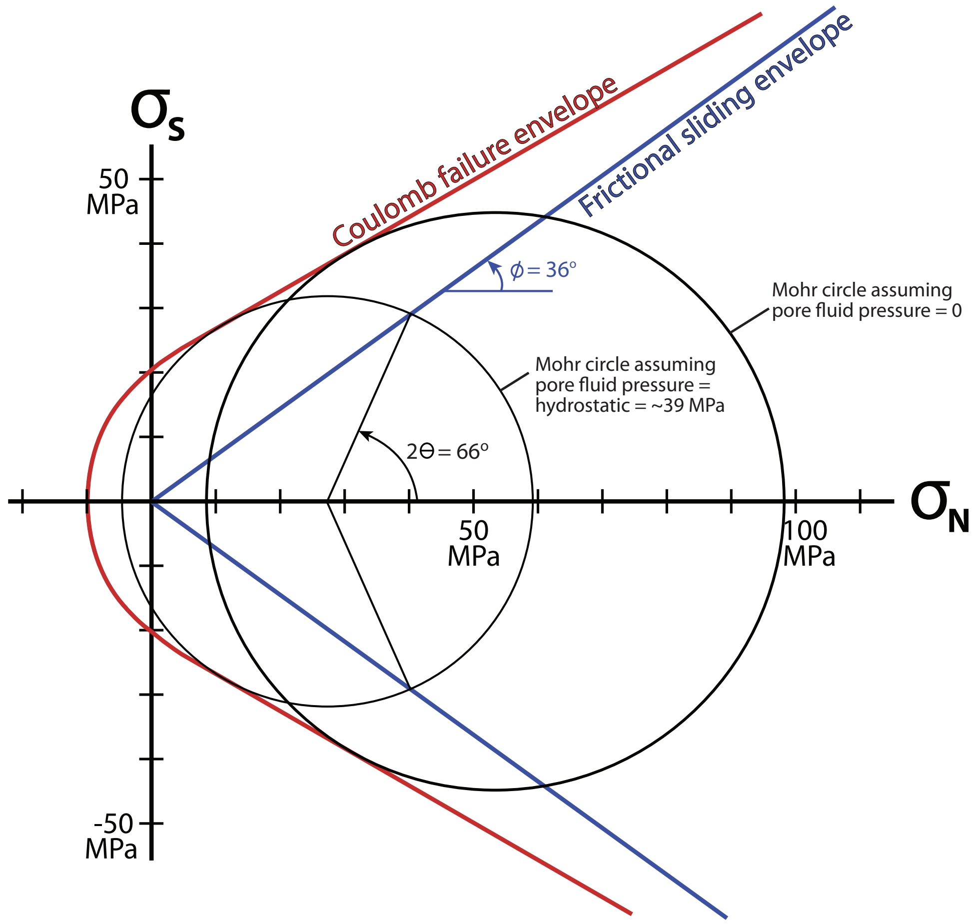
Hydrostatic stress at 4 km = (1,000 kg/m^3)(9.8 m/s^2)*(4,000 m) = 39.2 MPa. Shift σ_1 left by ~39 MPa; Mohr circle with effective σ_1 = 59 MPa will intersect Coloumb failure envelope if effective σ_3 = -5 MPa, so actual σ_3 = 35 MPa (-5+39).*

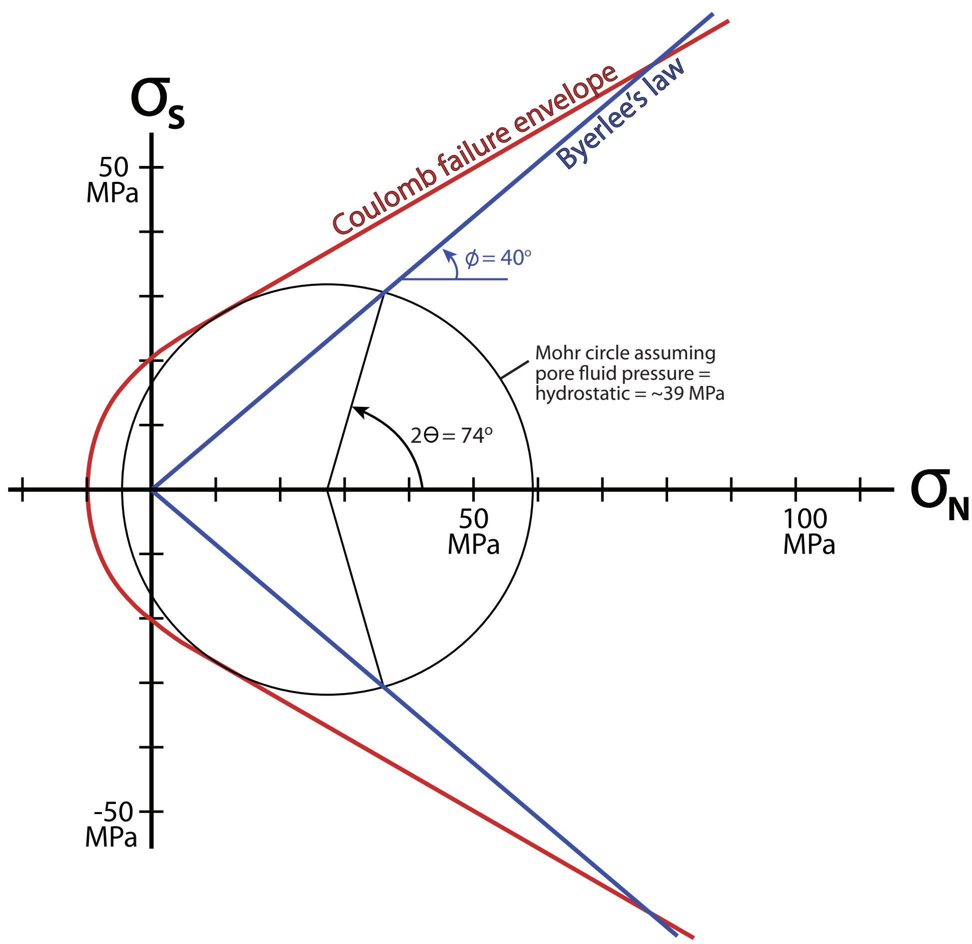
9) On the Mohr diagram, draw a frictional sliding envelope that accounts for frictional lockup on the Rattlesnake fault at its current orientation, assuming hydrostatic pore fluid pressure. Based on the slope of this envelope, what is the coefficient of friction for the Rattlesnake fault? How does this value compare to Byerlee's experimental values? If the Rattlesnake fault obeyed Byerlee's law (σ_s=0.85*σ_n), what would have been the dip of the fault when it locked up?

Draw a frictional sliding envelope that intersects the Mohr circle (from question 8) at 2Θ=66° (assuming the Rattlesnake fault locked up at ~33°). The slope of this envelope is ~36°, corresponding to a coefficient of friction of 0.73 (μ = tan φ = tan 36 = 0.73). This is about 14% less than the average coefficient of friction determined from Byerlee's experiments (0.85). If the Rattlesnake fault obeyed Byerlee's law, it would have locked up at ~37°.


500 m
A
30
Tc
29
26
Tc
27
28
Ts
Rattlesnake fault
Jackrabbit fault
27
25
28
27
61
58
Tc
450 m
26
Ts
A′
N
100 m
Explanation
Tc
Miocene conglomerate
Ts
Miocene sandstone
27
Strike and dip of sedimentary bedding
fault; arrow indicates dip direction and dip
58
scale: 1:2,500
contour interval = 10 m


A
A′
Elevation (m)
500
450
400
Tc
Ts


σS
50 MPa
-50 MPa
σN
50 MPa
100 MPa
Coulomb failure envelope
Frictional sliding envelope
ϕ = 36°
Mohr circle assuming pore fluid pressure = 0
Mohr circle assuming pore fluid pressure = hydrostatic = ~39 MPa
2Θ = 66°


σS
50 MPa
-50 MPa
σN
50 MPa
100 MPa
Coulomb failure envelope
Byerlee's law
ϕ = 40°
Mohr circle assuming pore fluid pressure = hydrostatic = ~39 MPa
2Θ = 74°

PART B:
Now onto some more complicated (real) geology. The map and cross section on the following pages are from a classic study by John Proffett on the Yerington mining district in Nevada. This area exposes at least three generations of faulting. Based on the map and cross section A-A', answer the following questions:

10) What kind of faulting has occurred here?

normal faulting

11) Based on cross-cutting relationships, give the name and orientation of one of the oldest faults exposed near A-A'. Give the name and orientation of one of the youngest faults.

Oldest: Singatse fault; dips ~10-13° E to ENE on map; inferred to be subhorizontal beneath Singatse Peak (based on drill hole)

Youngest: Montana-Yerrington fault (dips ~ 50° E based on map attitude; ~53° E based on cross section); Sales fault (dips ~ 58° E based on map attitude & cross section); or Range Front fault (dips ~ 59-66° E based on map attitudes, ~55-63° E based on cross section)

12) Which generation of faults have the most displacement? What is the largest amount of displacement on any individual fault?

The oldest generation has the most displacement; the largest fault is the Singatse fault with ~4,000 m displacement.

13) Assuming the oldest faults formed when the Tertiary volcanic and sedimentary rocks in the area were horizontal, what was the approximate initial dip of the oldest faults? (hint: determine the average bedding orientation in the fault hanging wall and footwall and restore to horizontal). Is this initial dip consistent with Andersonian theory?

Bedding in footwall and hanging wall of Singatse fault mostly dips ~45-55° W, indicating that the Singatse fault initiated at a dip of ~50-65°E. Yes, this is roughly consistent with Andersonian theory.

14) Assuming the second generation of faults (e.g. near Singatse Peak) obeyed Andersonian mechanics (and have rotated to its current orientation), at what angle did the oldest generation of faults cease to slip? At what angle did the second generation of faults cease to slip? Are these angles roughly consistent with Byerlee's law (where $\sigma_s=0.85*\sigma_n$)? (e.g. see your answer to question 9 in Part A)

The second generation of faults dip ~23-28°E where they cut the subhorizontal Singatse fault. If these faults initiated with an Andersonian ~60° dip, they must have cut the Singatse fault when it dipped ~32-37°. This second generation of faults are cut by the youngest generation of faults, which mostly dip ~50-60° E. Assuming this youngest generation initiated with a ~60° dip, the second generation of faults became inactive and

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15) In his 1977 paper published on this area, Proffett indicates that clay gouge is present along faults in this area. In addition, based on structural reconstructions, the Singatse fault in this area must have been >10 km deep where it was cut by younger faults. Given this information, why may the fault lockup angles you inferred in question 14 differ from those predicted by the relationship $\sigma_s=0.85*\sigma_n$? Take a look at Byerlee's experimental data below.

Clay has a lower coefficient of friction than most rocks (see vermiculite, montmorillonite, illite, and kaolinite points in plot below), so the development of clayey gouge will tend to weaken faults, allowing the normal faults to slip at lower angles. Also, the coefficient of friction decreases to ~0.6 above 200 MPa (2 kbar). The effective normal stress on the oldest generation of faults may have been ≥200 MPa, allowing the faults to slip at lower angles than that predicted by a coefficient of friction of 0.85.