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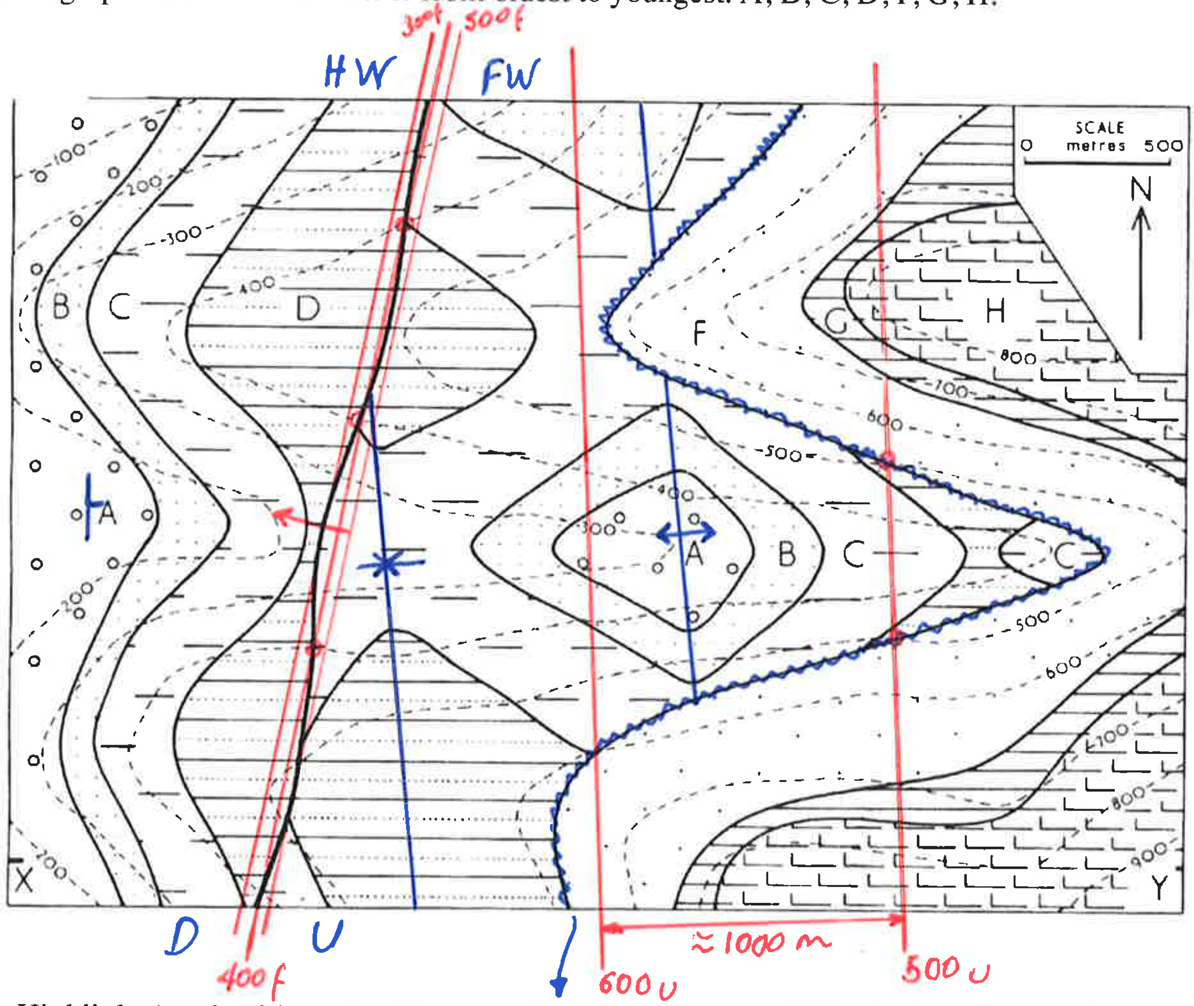
GEO210 Structural Geology
Final test. November 22, 2019

This test is closed book and closed notes. You have two hours to complete the test. Please be sure to show all your work. The total value of the test is 100 points. The point value of each question is shown.

Question 1 (30 points): The map below includes all the structural features introduced in the class: folds, a fault, and an unconformity. Contours are topographic elevation. The stratigraphic order of the units is from oldest to youngest: A, B, C, D, F, G, H.



a. Highlight (mark with a color) the unconformity in the map. What is the strike and dip of the units above the unconformity?

~~~ : unconformity

Strike : 357°

(RHR)

Dip = $\operatorname{atan}\left(\frac{100\ m}{1000\ m}\right) \approx 6°$
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b. Draw on the map the axial traces of the folds below the unconformity. Use appropriate symbols to indicate anticlines and synclines.

See map ↔ anticline

∗ syncline

c. Indicate on the map the dip direction of the fault, the hanging wall (HW) and footwall (FW), and the fault blocks that moved down (D) and up (U). What kind of fault is this?

← : fault dip (towards the west)

HW, FW: Hanging wall and footwall

D : Down

U : Up

Hanging wall has younger unit D against older unit C in footwall : Normal fault

e. Write a BRIEF geological history of the area portrayed by the map, giving the order of events producing these structural features.

1. ABCD and E? were deposited
2. Then they were folded (anticline and syncline)
3. Then they were faulted
4. Then E was eroded and FGH were deposited
5. A to H were tilted 6° to the east

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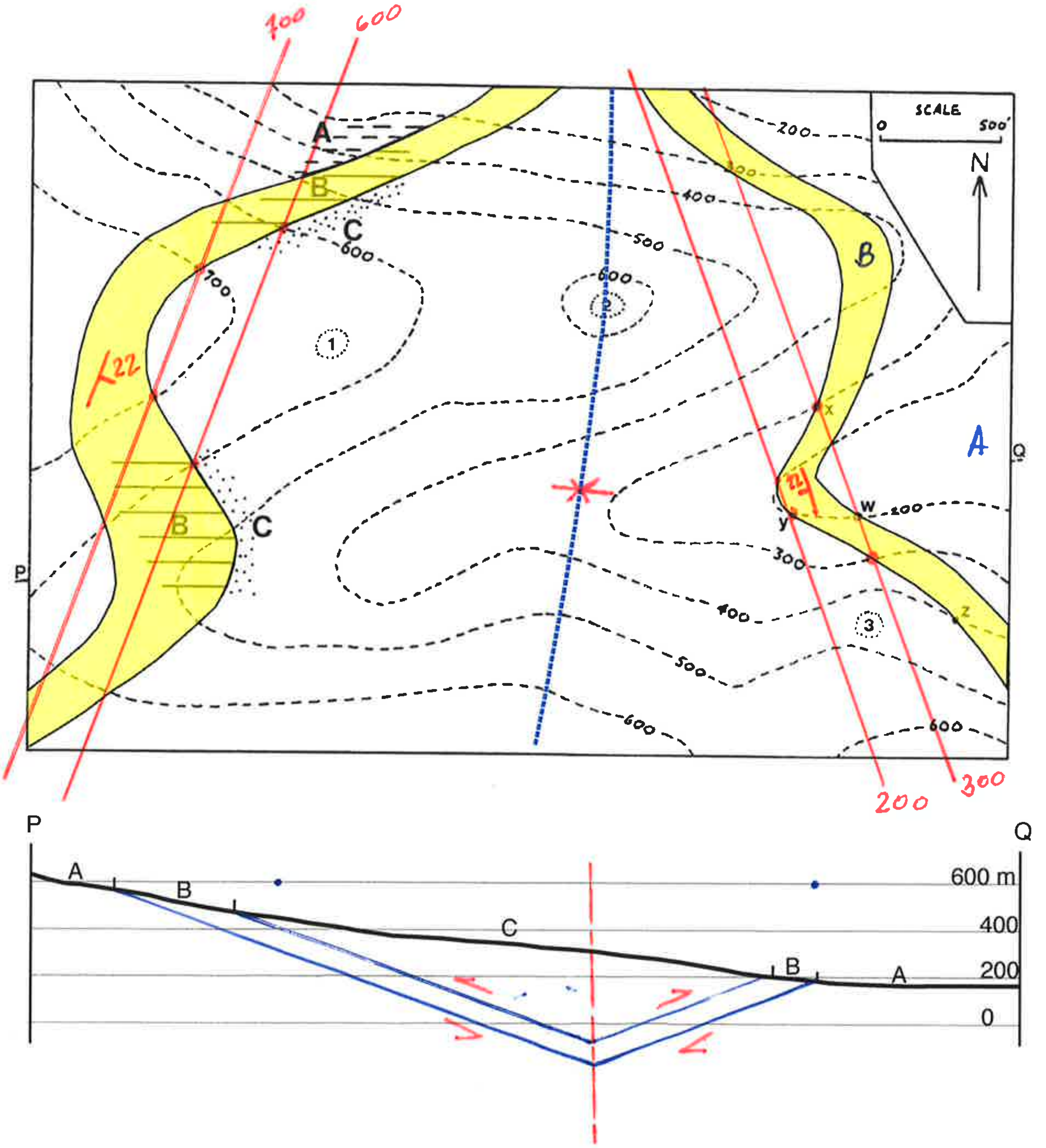
Question 2 (30 points): The map below shows an area in the Appalachian Valley and Ridge Province of western Maryland. One limb of the fold has a strike and dip (right hand rule) 020/22 and an apparent dip of 20° along section P-Q. The other limb has a strike and dip (right hand rule) 158/22 and an apparent dip of 21° along section P-Q. The dashed blue line is the axial trace of the fold, and the topographic profile and contacts along the section are provided.



a. Which limb has the orientation 020/22 and which has the orientation 158/22? Show this with strike and dip symbols in unit B on the map.

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b. What kind of fold is this? Indicate this on the axial trace with the appropriate symbol.

Syncline

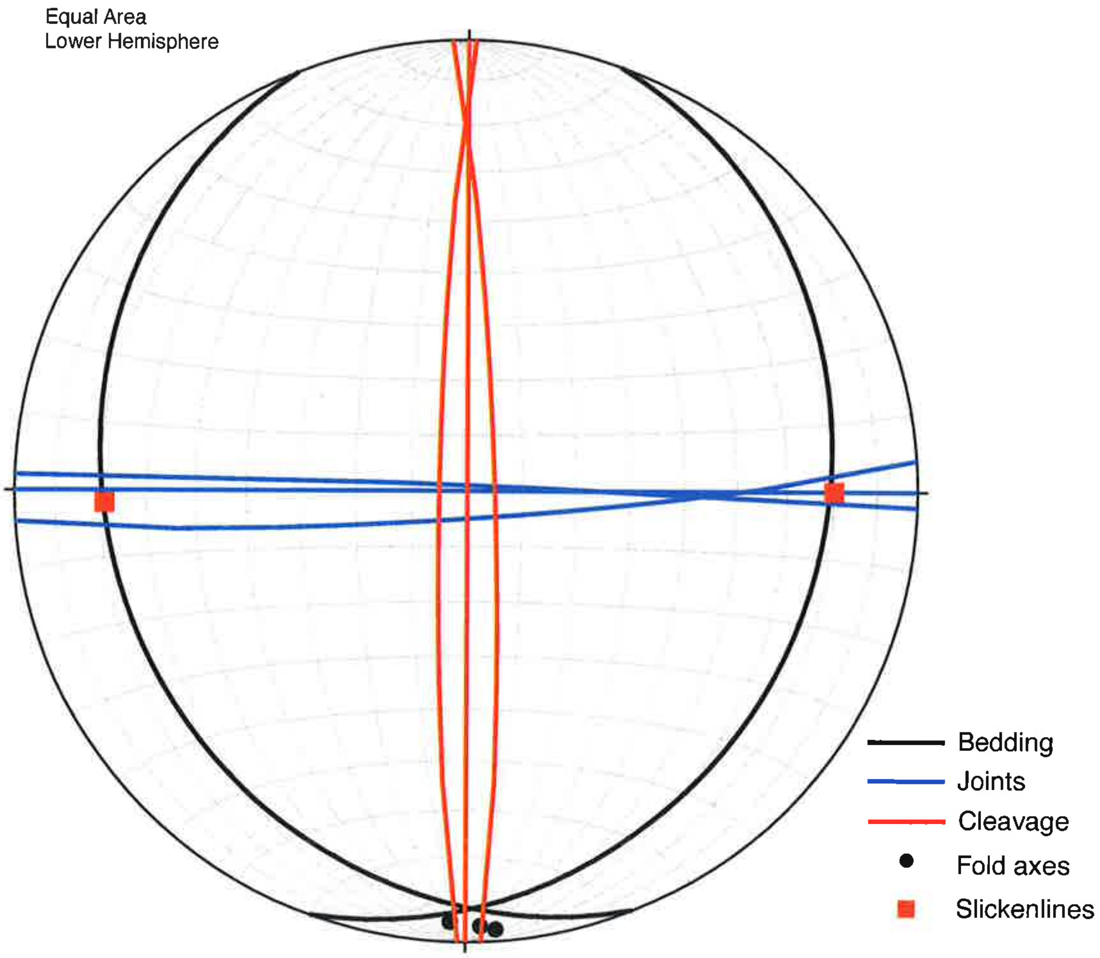
c. Draw an ACCURATE cross section along P-Q using the provided topographic profile and contacts above.

See cross section

d. Three outcrops within the sandstone unit C (1, 2 and 3 on the map) showed the following minor structures (planes orientations are right hand rule):

	Outcrop 1	**Outcrop 2**	**Outcrop 3**
Joints	086/85	272/89	090/90
Minor fold axes	178/04	182/05	176/03
Cleavage	181/85	000/90	358/85
Slickensides	268/21	----	090/20

These data are plotted on the stereonet below:



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What part of the fold does the intersection of the two limbs represent?

Fold axis (and fold hinge)

Fold axis plunges SOUTH

e. What is the relationship of the cleavage to the fold? What type of cleavage is this?

The cleavage contains the fold axis and bisects the fold limbs. It is therefore parallel to the axial plane of the fold. It is "axial planar cleavage"

f. What is the relationship of the joints to the fold? How did the joints form?

The joints are perpendicular to the axial plane of the fold. They were formed by extension parallel to the fold axis.

g. What is the relationship of the slickensides to the fold and why? Why were no slickensides observed at outcrop 2?

The slickensides are on the bedding planes and they trend along the beds' dip direction. They were formed by "layer parallel slip". There are no slickensides in outcrop 2 because at the hinge of the syncline there is no slip (shear) between the layers.

h. What is the relationship of the minor fold axes to the fold? What symmetry (M, S, or Z) would the minor folds have at outcrop 1, 2, and 3?

The small folds' axes are parallel to the fold axis. Their symmetry is as follows:

outcrop 1: Z   outcrop 2: M   outcrop 3: S

Looking along the fold axis

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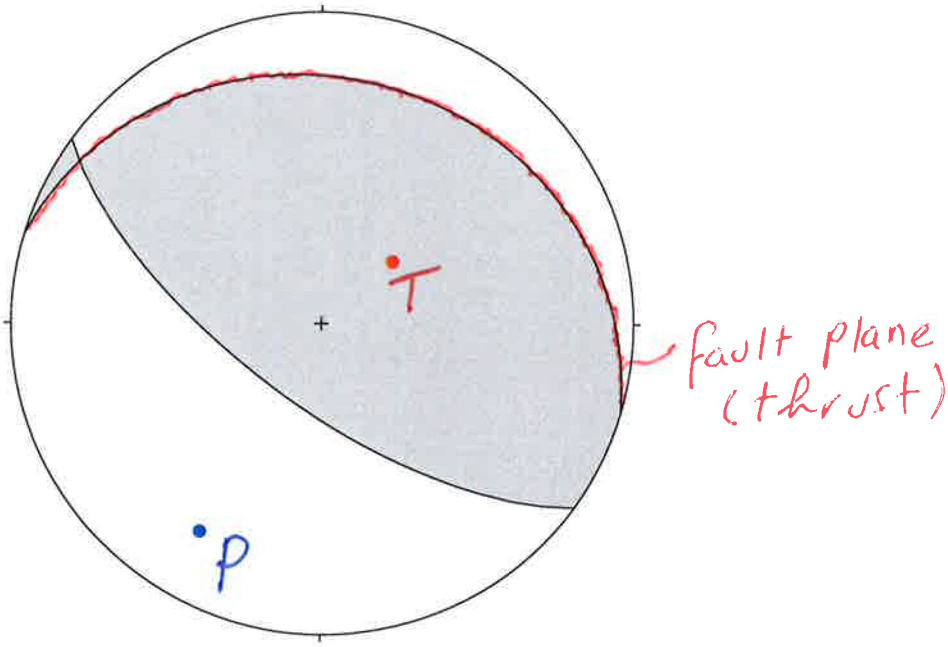
Question 3 (20 points): The figure below shows the focal mechanism solution for the 2012-11-07, M7.4, Guatemala earthquake, at the interface between the subducting Cocos plate and the overlying Caribbean and North America plates. This was the worst earthquake to hit Guatemala in decades with a death toll of 44.



a. What style of faulting is depicted by the figure?

Reverse (thrust) faulting

b. Mark the fault plane in the figure. What is its approximate orientation (strike/dip)?

≈ 285/20° (RHR)

c. Label the P and T axes in the figure. In a cross section perpendicular to the strike of the fault, what are the angles that the P and T axes make with the fault plane?

They make 45° with the fault plane

d. Earthquake seismologist refer to the P and T axes as pressure and tension, respectively. But what are exactly these axes in terms of strain?

They are the long and short axes of the infinitesimal strain ellipse.

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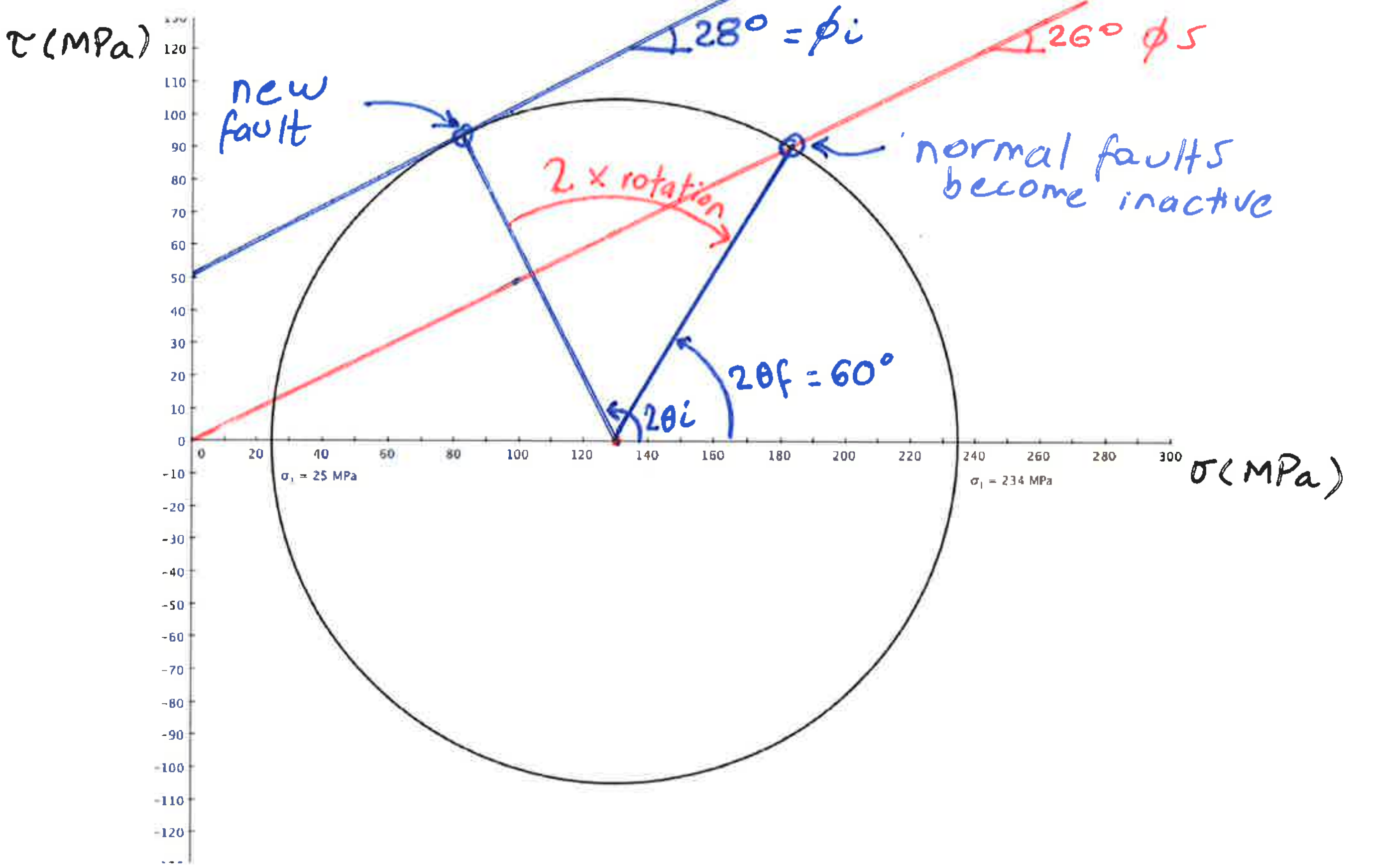
Question 4 (20 points): In a region of intracontinental rifting, the extension occurs via domino faulting. In this area, the angle of internal friction is 28°and the cohesion c is 50 MPa, the angle of sliding friction is 26°, and the rock density is 2600 kg/m³. The state of stress at the onset of a new fault is shown in the Mohr Circle below:



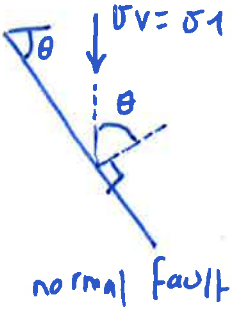
a. How deep in the crust would you expect to find the stresses represented on the Mohr Circle? Normal faulting regime, therefore $\sigma_1 = \sigma_v$

$$234 \approx 2.6 \times 10 \times z$$

$$9 \text{ km} \approx z \quad (\text{at} \approx 9 \text{ km depth})$$

b. What is the initial dip angle (ϕ_i) of the normal faults? θ

$$\theta_i = 45 + \frac{\phi_i}{2} = \underline{59°}$$ Anderson's theory of faulting



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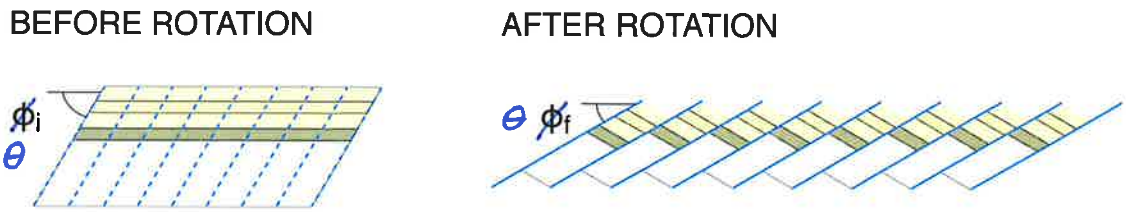
c. Because of domino faulting, the normal faults will rotate to a lower dip angle (see below where ~~ϕ_i~~ θ and ~~ϕ_f~~ θ are the initial and final fault dip angles). Using the Mohr circle above, determine how much the domino faults will rotate before they become inactive and new sets of faults begin to form.



$\theta_i = 59°$

$2\theta_f = 60° \Rightarrow \theta_f = \underline{30°}$

The domino faults will rotate $59 - 30 = \underline{29°}$ before they become inactive.