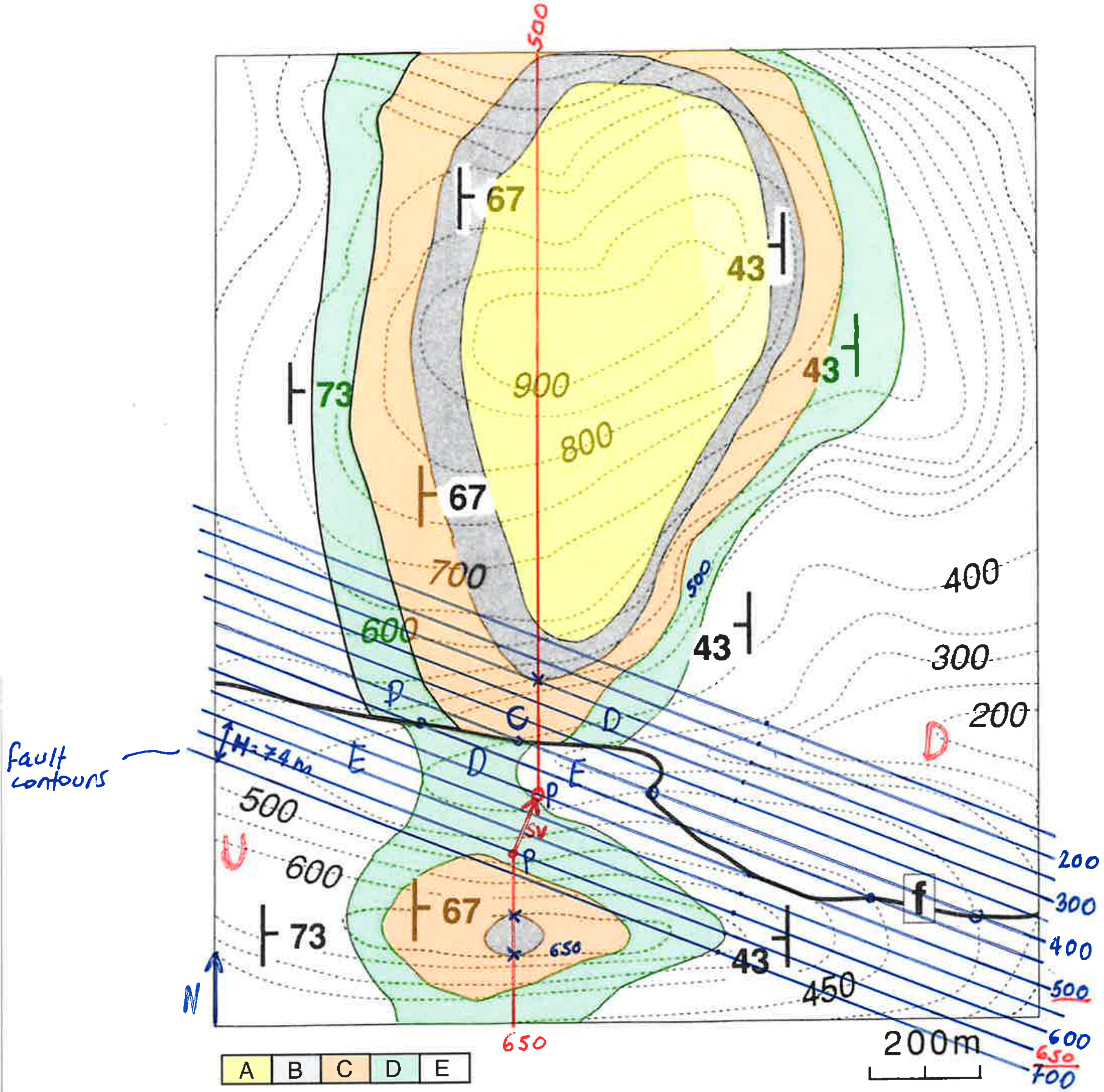
Student Name: Fasit

GEO210 Structural Geology
Final test. November 13, 2020

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 (25 points): In the geological map below, the fold predates the fault:



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a. What is the stratigraphic order of units A (yellow) to E (white)? What kind of fold outcrops in the area?

E – D – C – B – A
↑ Oldest ↑ Youngest

b. Mark the upthrown (U) and downthrown (D) fault blocks.

C in northern block against D in southern block
D in northern block against E in southern block
Younger in northern block against Older in southern block
Northern block: Down ; Southern block: Up

c. Draw structure contours on the fault and determine its strike and dip.

Blue lines

Strike: 291

Dip: $\text{atan}\left(\frac{100}{74}\right) = 53.5° \approx 54°$ (RHR)

d. Draw the fold hinge at the contact between units B (gray) and C (orange) on both sides of the fault. Notice that since the fold limbs have the same strike, the fold hinge is horizontal and parallel to the strike of the limbs. Mark the intersection of the fold hinge with the fault on both sides of the fault. These are piercing points.

See red hinge lines. Northern one is at elevation 500 m and intersects the fold at 500 m

Southern one is at 650 m and intersects the fold at 650 m

Piercing points are marked as P

e. Draw the fault slip vector. What kind of fault is this? What is the fault throw and heave?

Slip vector is perpendicular to the fault and therefore the slip is dip-slip. The fault is a normal fault (hangingwall downwards) and the throw is 150 m (650 - 500), and the heave is 110 m (horizontal distance of SV)

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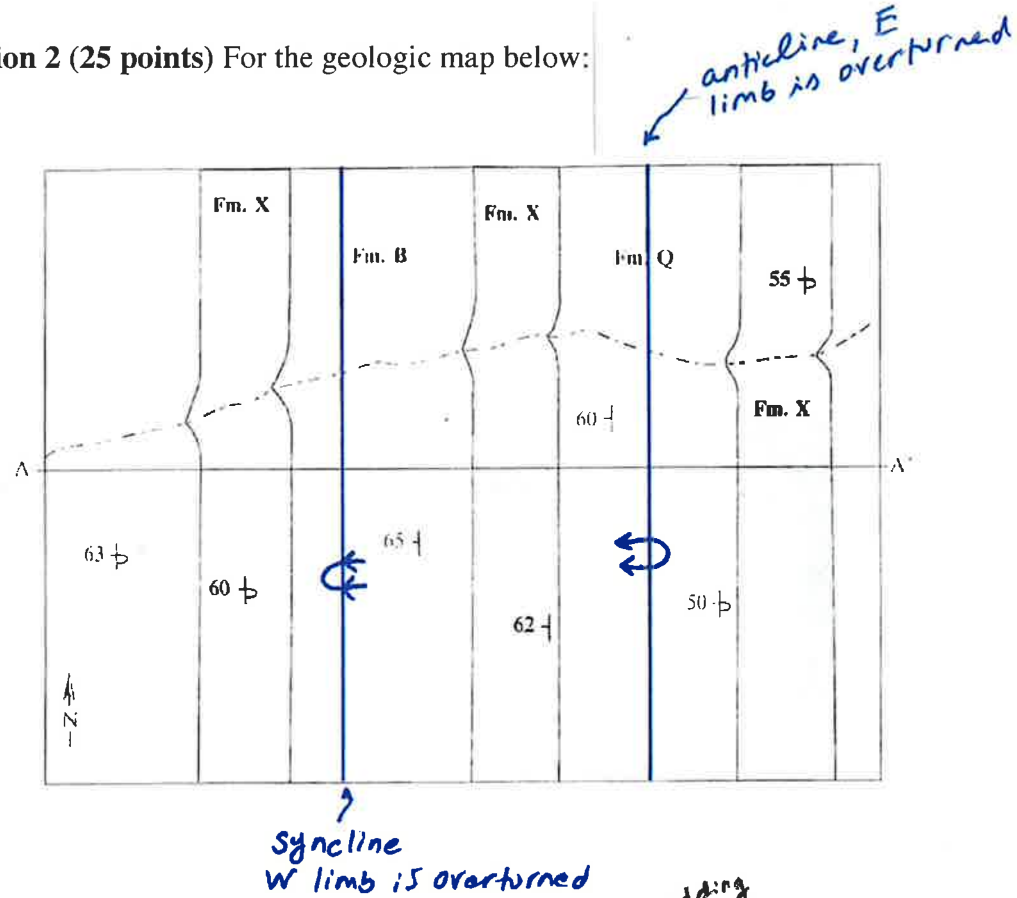
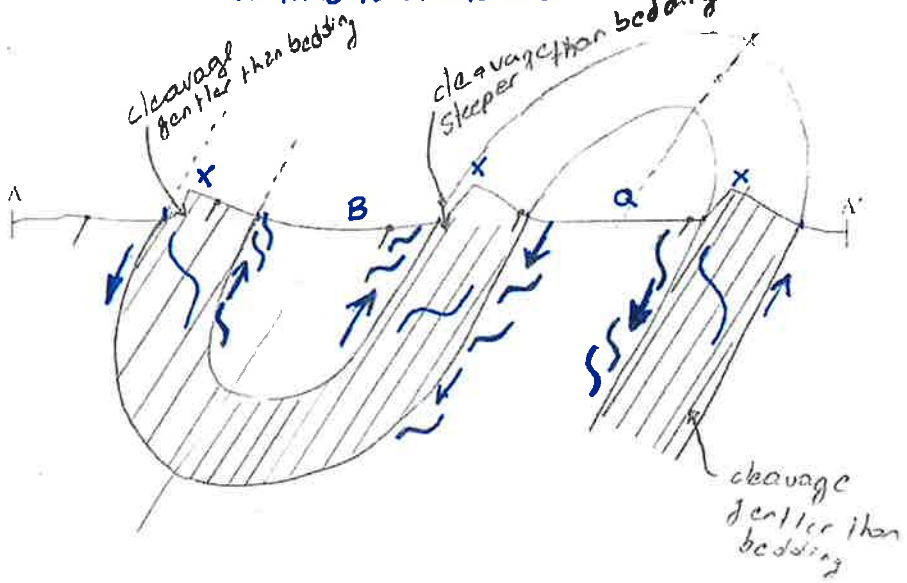
2. Question 2 (25 points) For the geologic map below:





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a. Draw the axial fold traces in the map. Make sure to label them with their correct symbols.

b. Complete cross section A-A'

c. Formation X displays axial planar cleavage. In the cross section A-A', draw the cleavage in Formation X. Do this for all folds along the section.

d. Slickenlines on the bedding surfaces indicate that the folds formed by flexural slip folding. In the cross section A-A', indicate the sense of shear along the beds. You can use the top and bottom of Formation X for this purpose.

e. Sigmoidal veins are present in Formations Q and B. Draw these veins in the cross section A-A'. Make sure to do this for all folds along the section.

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3. Question 3 (25 points): The gradient of vertical stress in a sedimentary basin is 23 MPa/km.

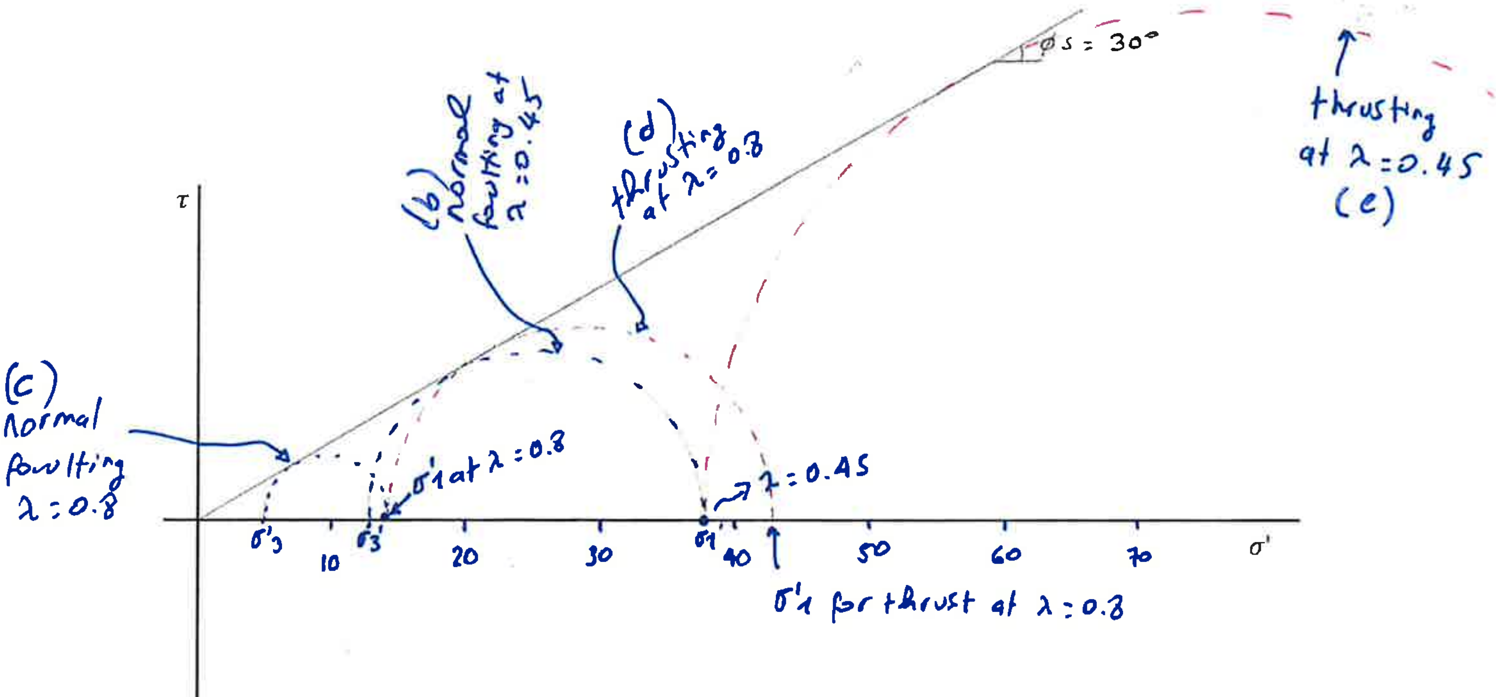
a. What is the vertical stress at 3 km depth? If the pore-fluid pressure ratio λ (pore fluid pressure/vertical stress) at this depth is 0.45, what is the effective vertical stress? (remember that the effective stress is equal to the normal stress minus the pore-fluid pressure).

$\sigma v = 23 \times 3 = 69$ MPa

$p = 0.45 \times 69 = 31.05$ MPa

$\sigma' v = 69 - 31.05 = \underline{37.95 \text{ MPa}}$

b. The basin is under extension and faulting is controlled by slip on preexisting, cohesionless crustal discontinuities with $\phi_s = 30°$. Using the Mohr circle diagram below, estimate the differential stress for normal faulting at 3 km depth and λ = 0.45 (notice that in the Mohr circle, the horizontal axis is effective stress σ').



(b) $\sigma'1 = \sigma v$

$\sigma'1 - \sigma'3 = 25$ MPa (circle (b))

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c. Suppose that the pore fluid pressure ratio λ at 3 km depth increases to 0.8. What is the differential stress for normal faulting at this depth and these higher pore-fluid pressures? Use the Mohr circle diagram above to solve this problem.

$P = 69 \times 0.8 = 55.2$ MPa

$\sigma'_V = 69 - 55.2 = 13.8$ MPa

$\sigma'_1 - \sigma'_3 \approx$ 9 MPa (circle (c))

d. At a later time, the basin is positively inverted such that the basin is under horizontal compression, and normal faults can be reactivated as reverse faults. What is the differential stress for reverse faulting at 3 km depth and with λ = 0.8? Use the Mohr circle diagram above to solve this problem.

for a thrust: $\sigma'_3 = \sigma'_V = 13.8$ MPa

$\sigma'_1 - \sigma'_3 = 28 - 30$ MPa (circle (d))

e. Do high pore-fluid pressures facilitate the reactivation and inversion of the normal faults as reverse faults?

(circle(e))

Yes. If λ would be 0.45, the differential stress ($\sigma'_1 - \sigma'_3$) for reverse faulting would be much higher than for λ = 0.8.

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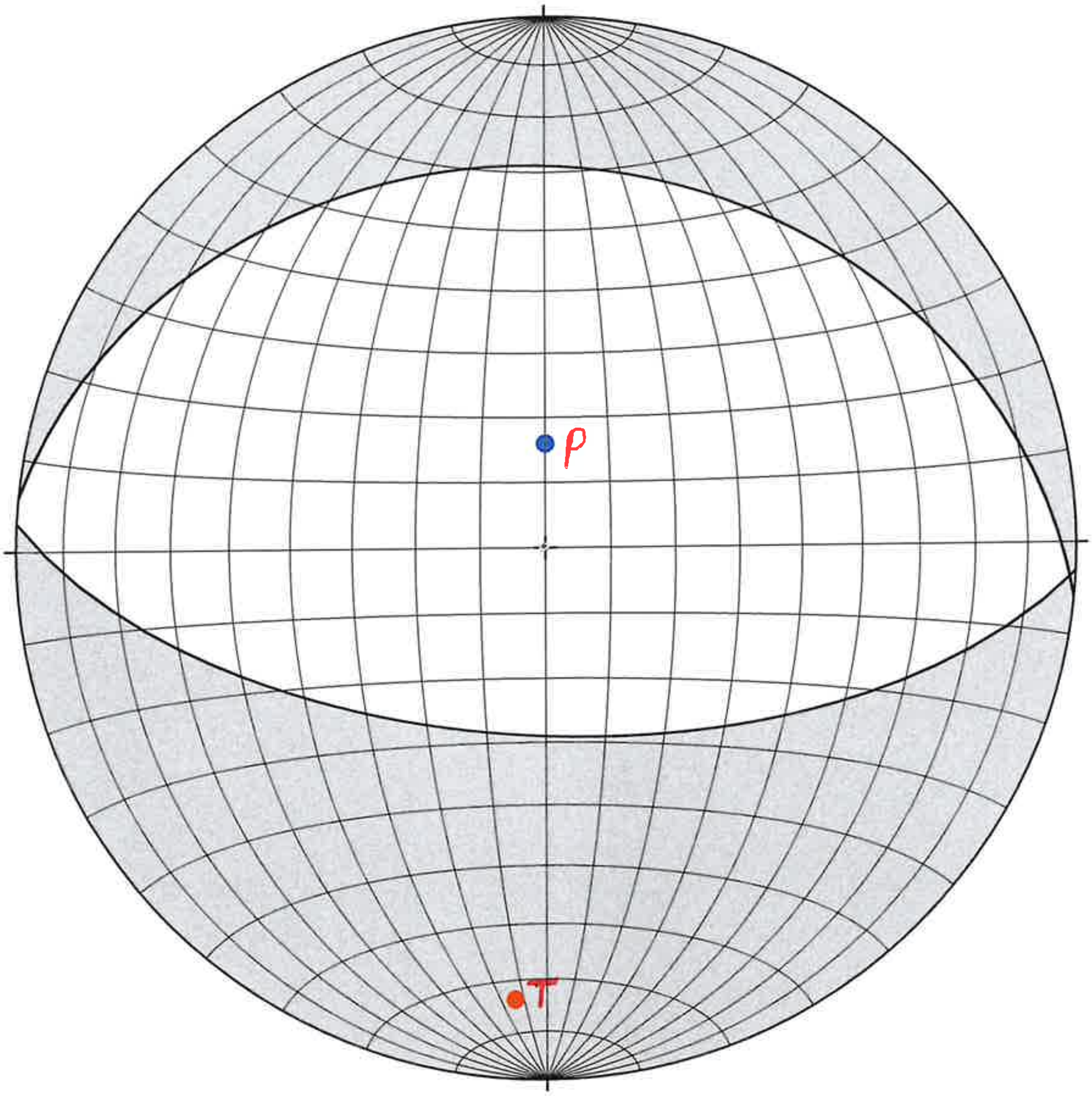
Question 4 (25 points): The figure below shows the focal mechanism or beachball diagram for the M 7.0 Neón Karlovásion earthquake, off the coast of Greece and Turkey, on October 30, 2020. A stereonet grid is superimposed so you can solve questions (d) and (e) (using transparent paper and a pin).



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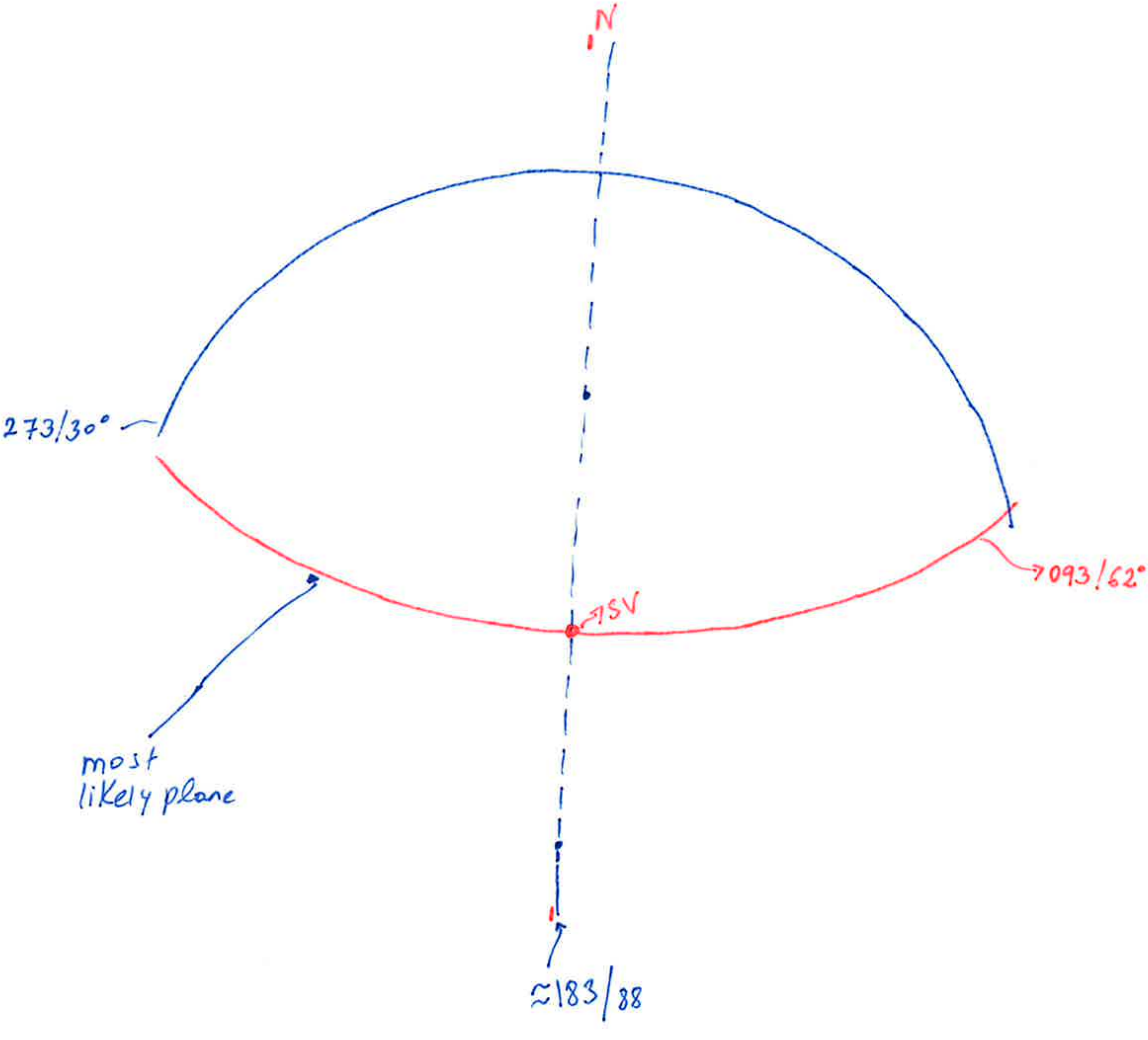

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a. Mark the P and T axes in the diagram

See Diagram

b. What do the P and T axes stand for? What is the angle between these axes and the fault slip vector?

They stand for pressure and tension, but they are actually the principal extension and shortening axes of infinitesimal strain. They are at <u>45°</u> from the slip vector.

c. What kind of faulting regime does the diagram suggest?

Normal faulting

d. Mark on the stereonet the most likely fault plane that generated the earthquake (consider the Anderson theory of faulting). What is the orientation of this fault plane?

The northern dipping fault dips 30°, while the southern dipping fault dips 62°. According to Anderson, normal faults formed at a dip angle of ≈ 60°. Therefore, the southern dipping fault seems more likely.

e. What is the orientation of the movement plane and of the fault slip vector?

approximately 183/88 (RHR)

Slip vector is about 185/60 (trend & plunge)

So the movement is mostly dip-slip.