# Plan of practical structural analysis course

| week | Content |
|---|---|
| Week one | Attitudes of Lines and Planes |
| Week two | Construction and interpretation of the Rose Diagram. |
| Week Three | Stereographic Projection of Structural Data (Planes, lines, and poles) |
| Week four | Stereographic Projection of Structural Data (Line of intersection of two planes and Angles within a plane) |
| *Week five* | Stereographic Projection of Structural Data (True dip from strike and apparent dip and Strike and dip from two apparent dips) |
| *Week six* | Mid semester exam |
| *Week seven* | Stereographic Analysis of Structural Data (The two-tilt problem) |
| *Week eight* | Stereographic Analysis of folded Rocks (Beta and Pi diagrams) |
| *Week nine* | Brittle failure (Mohr circle of stress) |
| *Week ten* | Brittle failure (The failure envelope) |
| *Week eleven* | Strain measurement (longitudinal and shear strain) |
| *Week twelve* | Kinematic indicators |

*Week one*

*Attitudes of Lines and Planes*

## Task 1.1: How to determine the attitudes of planar and linear structures using Bruton compass

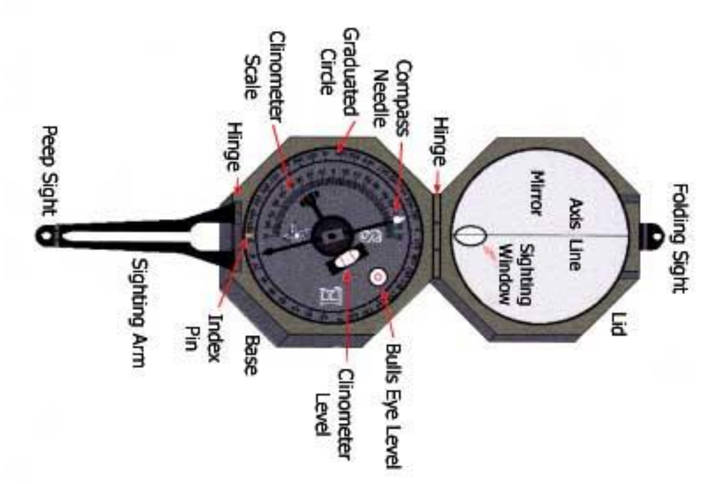
**Attitude:** The orientation in space of a line or plane.

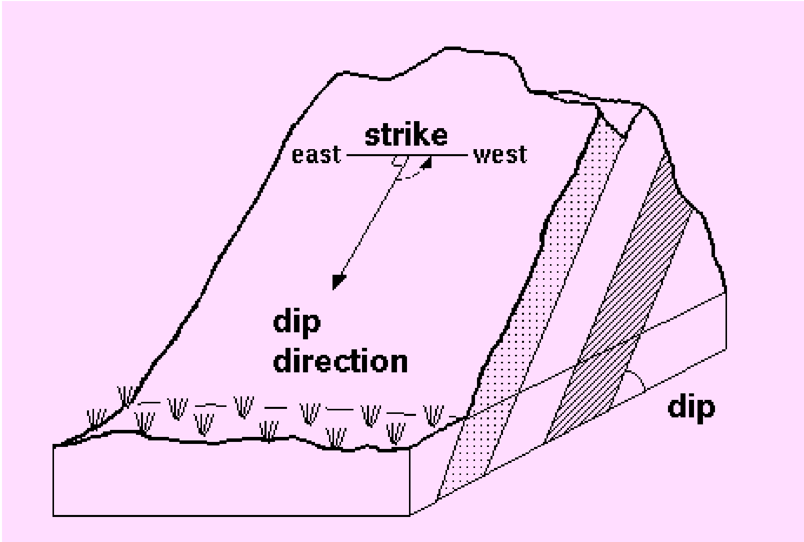
**Bearing:** The horizontal angle between a line and a specified coordinate direction, usually true north or south; the compass direction or azimuth.
**Strike:** The bearing of a horizontal line contained within an inclined plane. The strike is a line of equal elevation on a plane. There are an infinite number of parallel strike lines for any inclined plane.
**Dip:** The vertical angle between an inclined plane and a horizontal line perpendicular to its strike.
**The direction of dip**: can be thought of as the direction water would run down the plane.

**Trend:** The bearing (compass direction) of a line. Non-horizontal lines trend in the down-plunge direction.
**Plunge:** The vertical angle between a line and the horizontal.
**Pitch:** The angle measured within an inclined plane between a horizontal line and the line in question. Also called rake.

**Apparent dip:** The vertical angle between an inclined plane and a horizontal line that is not perpendicular to the strike of the plane.

There are two ways of expressing the strikes of planes and the trends of lines. The **azimuth method** is based on a 360 clockwise circle; the **quadrant method** is based on four 90 quadrants.






**Problem 1.1:** Translate the azimuth convention into the quadrant convention, or vice versa.

a) N12° E
b) 298°
c) N86° W
d) N55° E
e) 126°
f) N37° W
g) 233°
h) 270°
i) 083°
j) N3° W

**Problem 2.1:** Circle those attitudes that are impossible

a) 314, 49 NW
b) 086, 43 W
c) N15 W, 87 NW
d) 345, 62 NE
e) 062, 32 S
f) 333, 15 SE
g) 089, 43 N
h) 065, 36 SW
i) N65W, 54 SE

**Problem 3.1:** Using Brunton compass determine the attitudes of plane (A) and line (B).

# *Week two*

## *Construction and interpretation of rose diagrams*

Rose diagrams, also called polar bar plots, are useful for showing azimuthal (directional) data.

Data used from field measurements, geological map, aerial photographs, and satellite images.

How to construct rose diagram

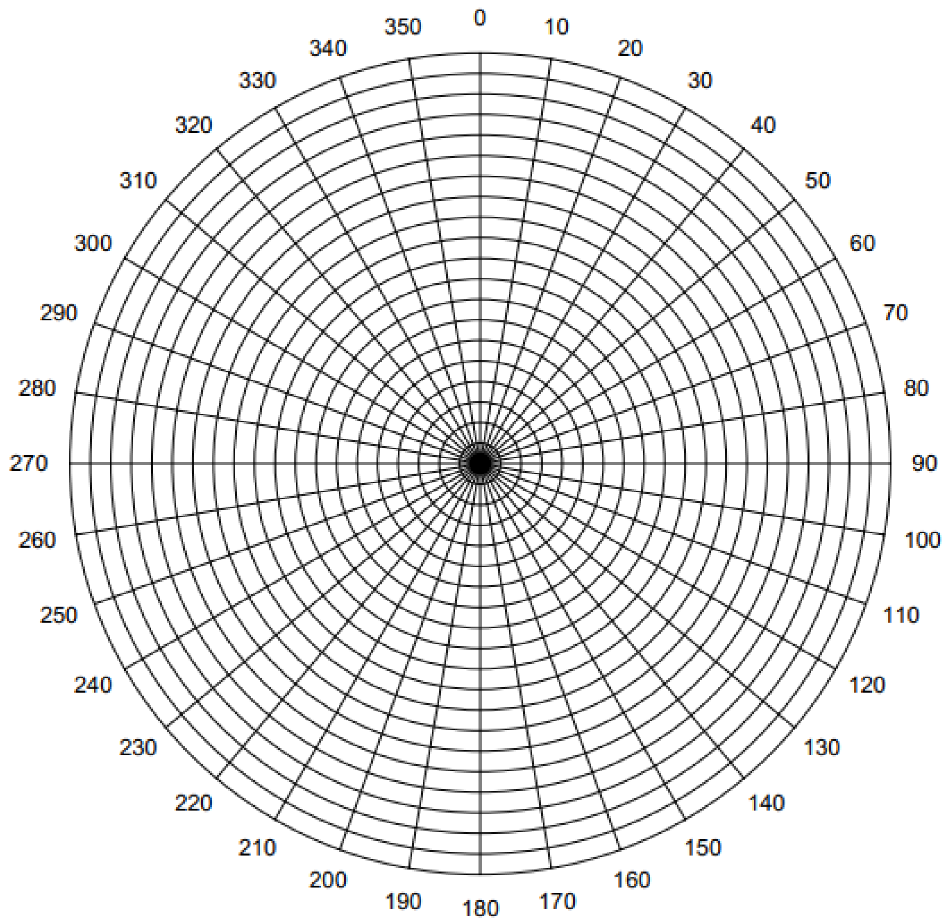
A- From geological maps, aerial photographs, and satellite images.
   1- Fix the map and put overlay over it.
   2- Trace the lineaments and number them.
   3- Make a grid with suitable interval
   4- Measure the length and angle of the lines due to the north.
   5- Put the measurements in the below table

B- From field data
   1- Measure the strikes and/or the bearings of structures.
   2- Analyze the directional data in the attached table.

### Task 2.2: Construction rose diagram from geologic map extracted data

**Problem 1.2**: From the following below data, construct rose diagram and determine the prominent structural trends.

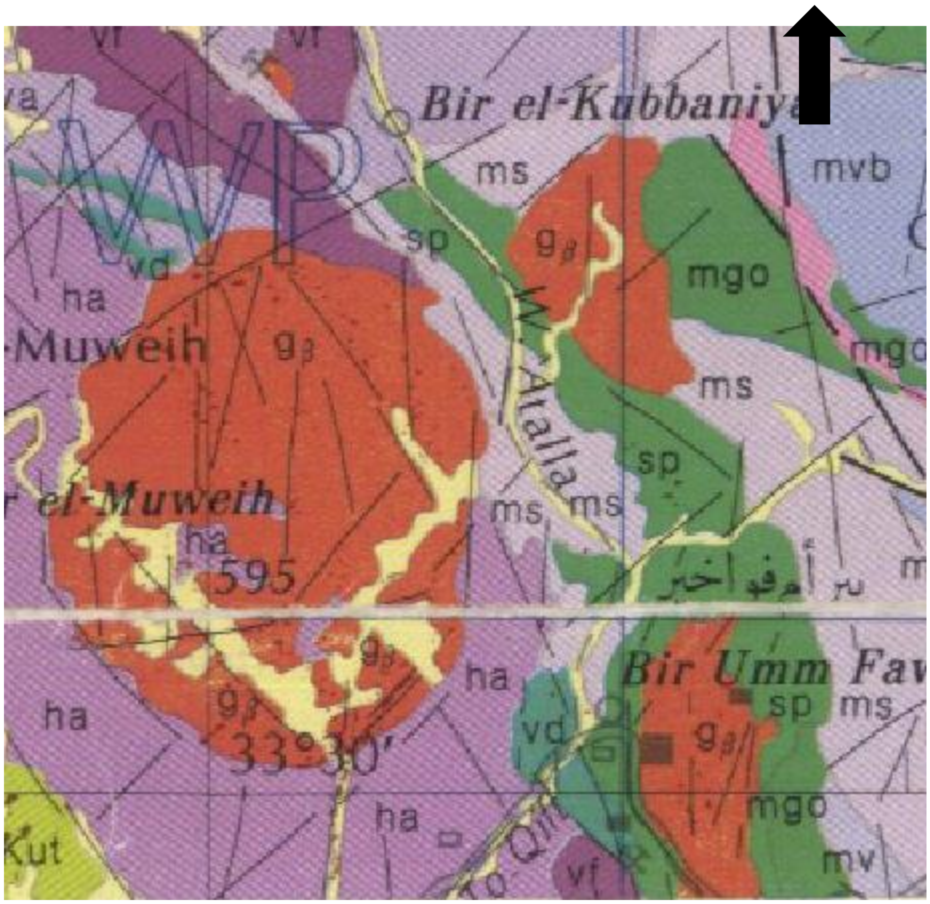
| E | | | | | W | | | |
|---|---|---|---|---|---|---|---|---|
| N | L | N % | L % | Azimuth | N | L | N % | L % |
| 3 | 5 | | | 0-10 | 22 | 28.5 | | |
| 12 | 19 | | | 10-20 | 11 | 14 | | |
| 19 | 28.2 | | | 20-30 | 6 | 7.8 | | |
| 28 | 46.1 | | | 30-40 | 21 | 32.2 | | |
| 30 | 22.7 | | | 40-50 | 26 | 38.3 | | |
| 50 | 103.9 | | | 50-60 | 28 | 40.9 | | |
| 15 | 29 | | | 60-70 | 30 | 44.2 | | |
| 16 | 25.9 | | | 70-80 | 23 | 30.5 | | |
| 0 | 0 | | | 80-90 | 44 | 75.3 | | |

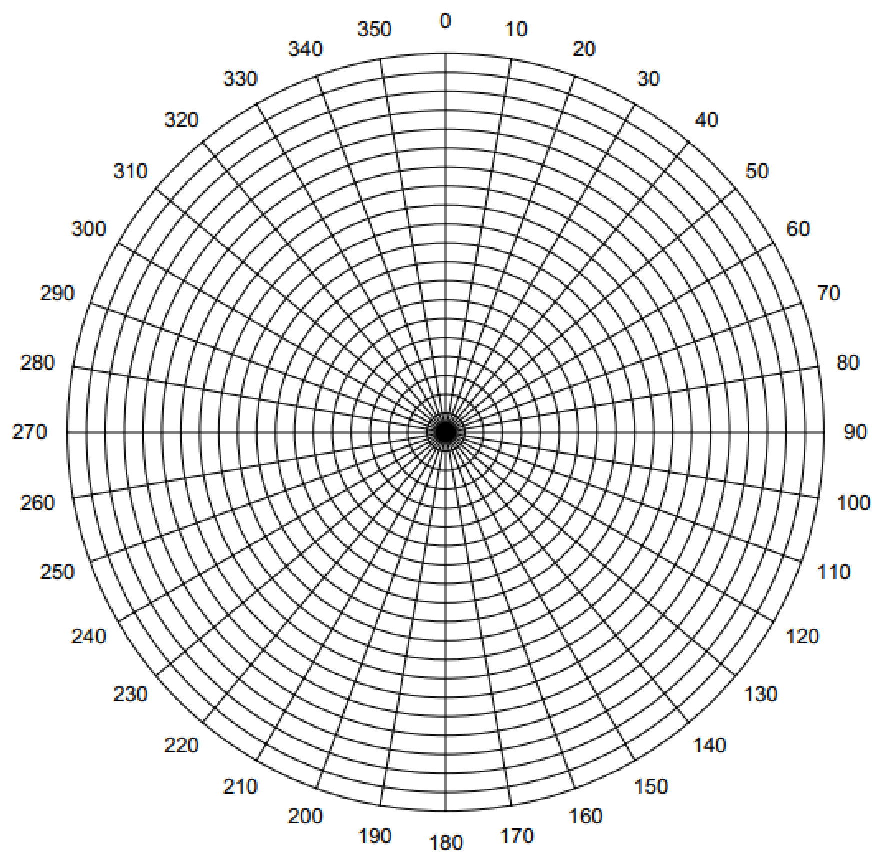



Blank rose to construct the rose diagram

## Task 2.2: Construction of rose diagram from geological map

**Problem 2.2**: You have a geological map for a part of the eastern desert of Egypt. Extract the lineaments and construct the rose diagram and determine the structural trends affecting the area





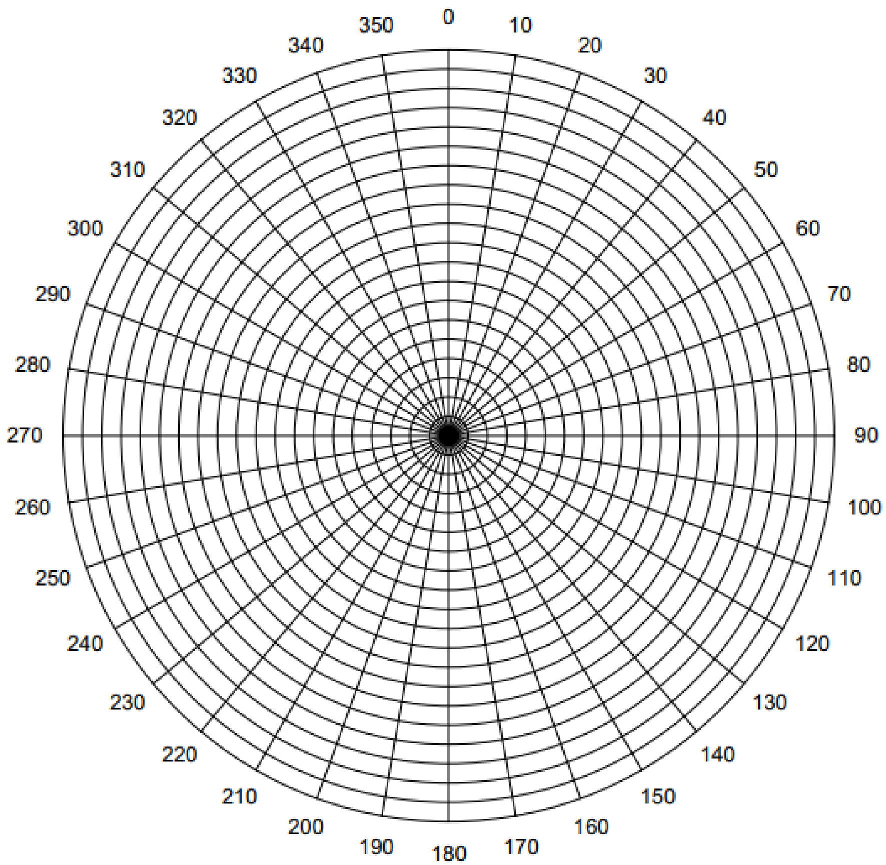

Blank rose to construct the rose diagram

## Task 3.2: Construction of rose diagram from field data

**Problem 3.2**: the table below show the orientations of fractures in a certain area, create the rose diagram and give comment about the structural trends prevailing in the area.

(Organize your azimuthal bins into 10-degree increments)

| Strike | Dip | Dip_Direction | | Strike | Dip | Dip_Direction |
|---|---|---|---|---|---|---|
| 345 | 65 | NE | | 60 | 83 | SE |
| 329 | 83 | SW | | 52 | 84 | SE |
| 328 | 75 | NE | | 68 | 84 | SE |
| 347 | 74 | NE | | 73 | 86 | NW |
| 330 | 32 | SW | | 57 | 70 | SE |
| 346 | 81 | NE | | 70 | 84 | NW |
| 277 | 74 | NE | | 47 | 80 | NW |
| 330 | 81 | NE | | 18 | 85 | NW |
| 347 | 78 | NE | | 38 | 40 | SE |
| 349 | 48 | NE | | 77 | 82 | SE |
| 292 | 84 | SW | | 11 | 27 | NE |
| 350 | 77 | NE | | 78 | 80 | NW |
| 351 | 15 | NE | | 48 | 85 | NW |
| 350 | 84 | SW | | 6 | 56 | SE |
| 349 | 83 | NE | | 39 | 66 | SE |
| 358 | 80 | SW | | 63 | 82 | SE |
| 300 | 82 | NE | | 68 | 80 | NW |
| 338 | 55 | NE | | 53 | 88 | SE |
| 343 | 78 | NE | | 17 | 83 | NW |
| 353 | 38 | NE | | 55 | 82 | NW |
| 348 | 83 | SW | | 72 | 80 | NW |
| 348 | 81 | NE | | 42 | 66 | SE |
| 287 | 82 | NE | | 83 | 75 | SE |
| 303 | 78 | NE | | 52 | 69 | NW |
| 328 | 75 | NE | | 1 | 88 | SE |
| 293 | 85 | SW | | 37 | 84 | NW |
| 348 | 76 | NE | | 68 | 75 | NW |
| 307 | 69 | NE | | 51 | 62 | NW |
| 316 | 43 | SW | | 4 | 88 | SE |
| 273 | 83 | SW | | 55 | 84 | SE |
| 298 | 18 | SW | | 18 | 82 | NW |
| 303 | 83 | NE | | 18 | 80 | SE |
| 342 | 76 | SW | | 54 | 82 | SE |
| 340 | 22 | SW | | 68 | 75 | SE |
| 280 | 38 | SW | | 32 | 85 | NW |
| 306 | 38 | SW | | 52 | 87 | NW |
| 285 | 82 | NE | | 72 | 50 | NW |
| 312 | 70 | SW | | 41 | 64 | SE |
| 298 | 18 | SW | | 84 | 90 | |
| 310 | 37 | SW | | 3 | 53 | NW |
| 313 | 83 | SW | | 53 | 70 | NW |
| 347 | 51 | NE | | 71 | 72 | NW |
| 20 | 78 | NW | | 15 | 68 | SE |
| | | | | 45 | 70 | NW |




Blank rose to construct the rose diagram

# *Week three*

## *(Stereographic Projection of Structural Data (Planes, lines, and poles)*

**Stereographic projection**

stereographic projection: involves the plotting of planes and lines on a circular grid or net.

**Objective**

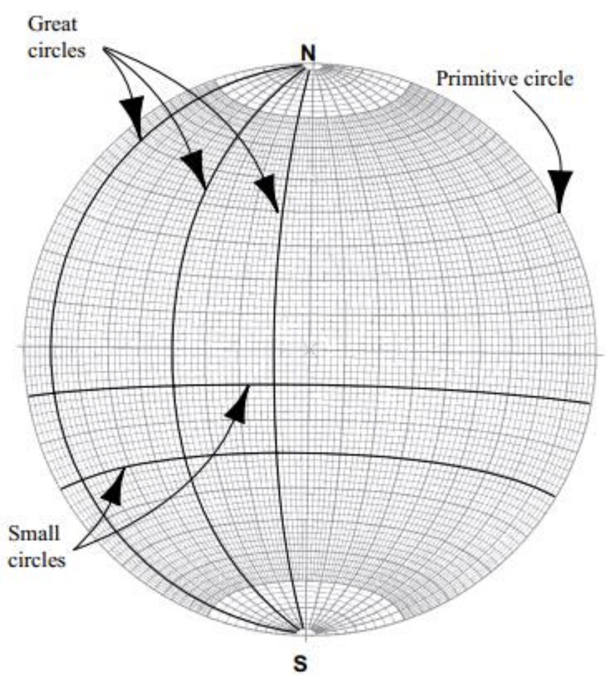
Use stereographic projection to quantitatively represent three-dimensional, orientation data (such as the attitudes of lines and planes) on a two-dimensional piece of paper.

**Elements of equal area net**

Great circles: The north–south lines

Small circles: The east–west lines

Primitive circle: The perimeter of the net



## Task 1.3: How to plot planes

Suppose a plane has an attitude of 315, 60SW. It is plotted on the equal-area net as follows:

1- Stick a thumbtack through the center of the net from the back, and place a piece of tracing paper over the net such that the tracing paper will rotate on the thumbtack. A small piece of clear tape in the center of the paper will prevent the hole from getting larger with use.

2- Trace the primitive circle on the tracing paper (this step may be eliminated later), and mark the north and south poles.

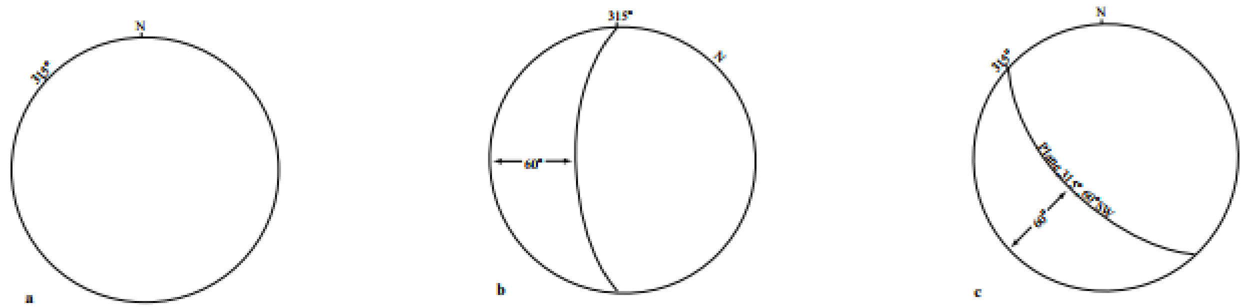
3- Find 315 on the primitive circle, mark it with a small tick mark on the tracing paper and label it 315 (Fig.a).

4- Rotate the tracing paper so that the N45W mark is at the north pole of the net (Fig. b).

5- Southwest is now on the left-hand side of the tracing paper, so count 60 inward from the primitive circle along the east–west line of the net and put a mark on that point.

6- Without rotating the tracing paper, draw the great circle that passes through that point (Fig. b).

7- Finally, rotate the paper back to its original position




**Problem 1.3**: Plot the following planes on the equal area net.

1- Plane having the formula N60° W/ 20° NE.
2- Plane dipping 70° to the N30°E.
3- Plane striking N 45°E and dipping 70° to the NE (Home problem 1-3)

**Task 2.3: How to plot lines**

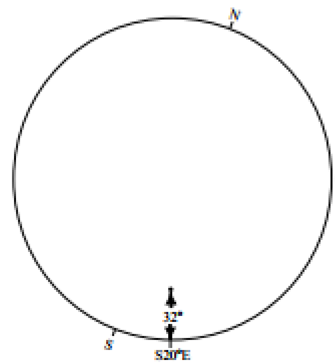
While a plane intersects the hemisphere as a line, a line intersects the hemisphere as a single point. Consider a line that has an attitude of 32, S20E. Here is how such a line projects onto the net:

1- Mark the north pole and S20E on the tracing paper.

2 -Rotate the S208E point to the bottom (‘‘south’’) point on the net. (The north, west, or east points work just as well. Only from one of these four points on the net may the plunge of a line be measured.)

3 -Count 32 from the primitive circle inward and mark that point.

4 -Rotate the paper back to its original orientation.



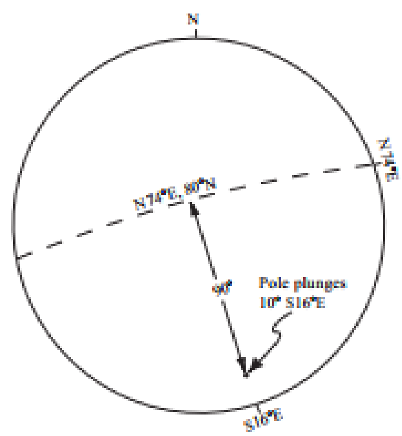

**Problem 2.3:** Plot the following planes on the equal area net.

1- A line plunging 40 to 210.
2- A line having the formula 20/ 080.
3- A line plunging 70 to 230 (Home problem 2-3).

## Task 3.3: How to plot a pole of a plane

By plotting the pole to a plane, it is possible to describe the plane's orientation with a single point on the net. The pole to a plane is the straight line perpendicular to the plane, 90 across the stereonet from the great circle that represents the plane. If a plane strikes north–south and dips 40 west, its pole plunges 50 due east. Suppose a plane has an attitude of N748E, 808N. Its pole is plotted as follows:

1-Mark the point on the tracing paper that corresponds to N74E. Then rotate the tracing paper so that this point lies at the north pole of the net, as if you were going to plot the plane itself. The great circle representing this plane is shown by the dashed line in.
2- Find the point on the east–west line of the net where the great circle for this plane passes, and count 90 in a straight line across the net. This point is the pole to the plane. Mark this point, record the plunge, and also make a tick mark where the east–west line meets the primitive circle. Then rotate the tracing paper back to its original position and determine the direction of plunge. the pole to this plane plunges 10, S16E.




**Problem 3.3**: Project the following planes and their poles:

1- Plane striking N 10○E and dipping 30○ to the NW.
2- Plane striking N 45○E and dipping 70○ to the NE (Home problem 3-3).

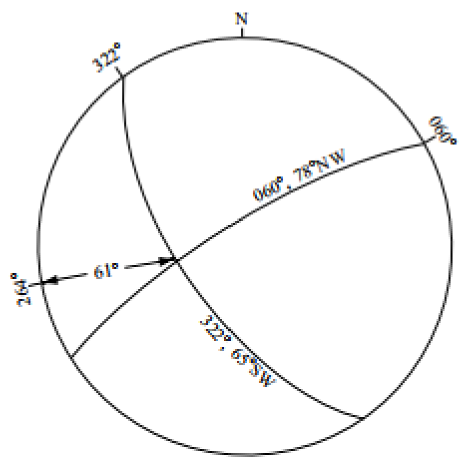
# Week four

## (Line of intersection of two planes and Angles within a plane)

**Task 1.4: Determining the attitudes of line of intersection of two planes**

Many structural problems involve finding the orientation of a line common to two intersecting planes. Suppose we wish to find the line of intersection of a plane 322, 65SW with another plane 060, 78NW. This line is located as follows:
1- Draw the great circle for each plane.
2- Rotate the tracing paper so that the point of intersection lies on the east–west line of the net. Mark the primitive circle at the closest end of the east–west line.
3- Before rotating the tracing paper back, count the number of degrees on the east–west line from the primitive circle to the point of intersection; this is the plunge of the line of intersection.

4-Rotate the tracing paper back to its original orientation. Find the bearing of the mark made on the primitive circle in step 2. This is the trend of the line of intersection. The line of intersection for this example plunges 61, 264.

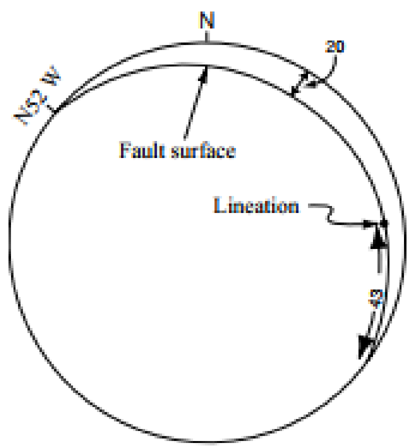



**Problem 1.4:**

1- A Vein striking N 20°E and dipping 30° NW intersects a bed which strikes N 45° W and dips 20° SW. What is orientation the line of intersection?
2- The two limbs of a fold strikes N50°W and N30°E and dips 35° northeasterly and 50° northwesterly respectively. What is orientation of the fold axis?

## Task 2.4: Measuring angles within a plane

Angles within a plane are measured along the great circle of the plane. , for example, each of the two points represents a line in a plane that strikes north–south and dips 50E. The angle between these two lines is 40, measured directly along the plane's great circle. The more common need is to plot the pitch of a line within a plane. Plotting pitches may be useful when working with rocks containing lineations. The lineations must be measured in whatever outcrop plane (e.g., foliation or fault surface) they occur. Suppose, for example, that a fault surface of N52W, 20NE contains a slickenside lineation with a pitch of 43 to the east. Figure 5.11b shows the lineation plotted on the equal area net.


**Problem 2.4:**

1- A Vein striking N 20°E and dipping 30° NW intersects a bed which strikes N 45° W and dips 20° SW. What is the rake of intersection measured in the plane of the vein
2- Two limbs of a fold strike N60°W and N40°E and hade 55° NE and 40° NW respectively. A fault striking N 70°W and dipping 60° NE intersects of this fold, what is the rake of the intersection of these two limbs in the fault plane.

# Week five

## True dip from strike and apparent dip and Strike and dip from two apparent dips

### Task 1.5: Determining true dip from strike and apparent dip

Two intersecting lines define a plane, so if the strike of a plane is known, along with the trend and plunge of an apparent dip, then these two lines may be used to determine the complete orientation of the plane. Suppose a fault is known to strike 010, and an apparent dip of the fault plane is measured to have a trend of 154 and a plunge of 35. The true dip of the fault is determined as follows:

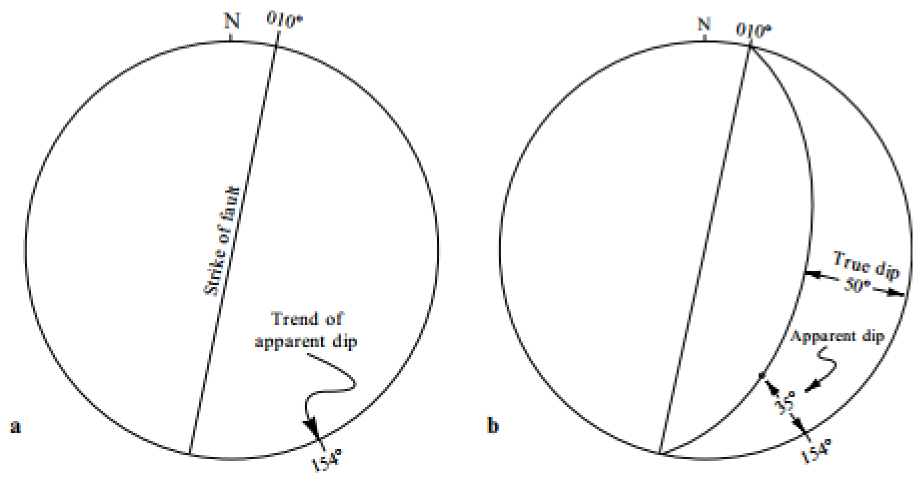
1- Draw a line representing the strike line of the plane. This will be a straight line across the center of the net, intersecting the primitive circle at the strike bearing.

2- Make a pencil mark on the primitive circle representing the trend of the apparent dip

3 -Rotate the tracing paper so that the point marking the apparent-dip trend lies on the east–west line of the net. Count the number of degrees of plunge toward the center of the net and mark that point. This point represents the apparent-dip line.

4 -We now have two points on the primitive circle (the two ends of the strike line) and one point not on the primitive circle (the apparent-dip point), all three of which lie on the fault plane. Turn the tracing paper so that the strike line lies on the north–south line of the net and draw the great circle that passes through these three points.

5- Before rotating the tracing paper back, measure the true dip along the east–west line of the net. The true dip is 50.




**Problem 1.5:**

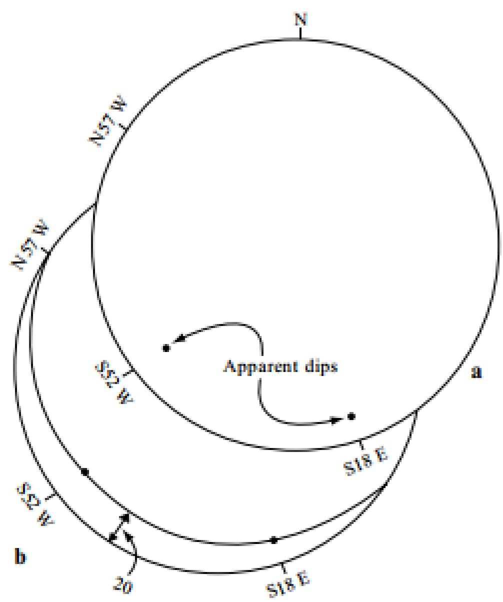
Along a vertical railroad cut a bed has an apparent dip of 20, 298. The bed strikes 067. What is the true dip?

## Task 2.5: Determining strike and dip from two apparent dips

Even if the strike of a plane is not known, two apparent dips are sufficient to find the complete attitude. Suppose two apparent dips of a bed are 13, S18E and 19, S52W. The attitude of the plane may be determined as follows:

1- Plot points representing the two apparent-dip lines.

2 -Rotate the tracing paper until both points lie on the same great circle. This great circle represents the plane of the bed, and the strike and dip are thus revealed. the attitude of the plane in this problem is N57W, 20SW.




**Problem 2.5:**

1- Find the strike and dip of the bed to these planes having two apparent dips 40° N80°W and 50° N 20° W.
2- In a rock cut along a bend in a rail road track, two apparent dips are read namely 20° to S 40° W and 35° to S 10° W. Find the direction and amount of true dip and write the formula of this bed.

# ***Week six***

*Mid semester exam*

# *Week seven*

## *The two-tilt problem*

**Task 6: How to identify the orientation of a bed affected by two episodes of tilting**

It is not uncommon to find rocks that have undergone more than one episode of deformation. In such situations it is sometimes useful to remove the effects of a later deformation in order to study an earlier one. Consider an angular unconformity separates Formation Y (N60W, 35NE) from Formation O (N50E, 70SE). Formation O was evidently tilted and eroded prior to the deposition of Formation Y, then tilted again. In order to unravel the structural history of this area we need to know the attitude of Formation O at the time Formation Y was being deposited. This problem is solved as follows:

1- Plot the poles of the two formations on the equal-area net.

2- We want to return Formation Y to horizontal and measure the attitude of Formation O. The pole of a horizontal bed is vertical, so if we move the Y pole point to the center of the net, Formation Y will be horizontal. Rotate the tracing paper so that Y lies on the east–west line of the net.

3- The Y pole can now be moved along the east–west line to the center of the net. This involves 35 of movement the O pole, therefore, must also be moved 35 along the small circle on which it lies, to O' (Fig. 5.15c).

4- O' is the pole of Formation O prior to the last episode of tilting. As shown in Fig. 5.15d, the attitude of Formation O at that time was N58E, 86SE.

**Problem 6:**

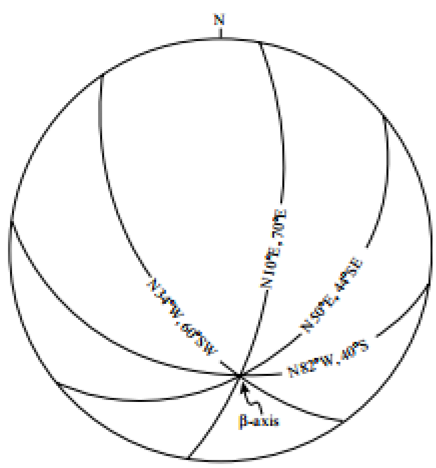
The beds below an angular unconformity have an attitude of 334, 74W, and those above 030, 54 NW. What was the attitude of the older beds while the younger beds were being deposited?

# *Week eight*

## *Stereographic Analysis of folded Rocks (Beta and Pi diagrams)*

**Task 1.7: H ow to determine the orientation of the fold axis using Beta (β) diagrams**

A simple method for determining the orientation of the axis of a cylindrical fold is to construct a β diagram. Any two planes tangent to a folded surface intersect in a line that is parallel to the fold axis. Such a line is called a b-axis. A β-axis is found by plotting the attitudes of bedding (or some other planar element) on an equal area net; the β-axis is the intersection line of the planes, which plots as a point on the net. Suppose, for example, that the following four foliation attitudes are measured at different places on a folded surface: N82W, 40S; N10E, 70E; N34W, 60SW; and N50E, 44SE. These attitudes are shown plotted on an equal-area net. The b axis, and therefore the fold axis, plunges 39, S7E. Few folds are perfectly cylindrical, so the great circles will rarely intersect perfectly, even if the folds have a common history. When data from areas with different folding histories are plotted together, distinctively different β-axes will appear.

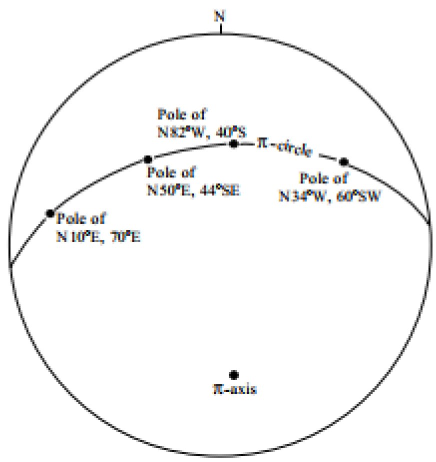



**Problem 1.7:**

The following three foliation attitudes are measured at different places on a folded surface 100, 50 SW, 190, 70 NW, and 048, 78 SE. Determine the orientation of the fold axis using β diagram method. (Answer= 49/215)

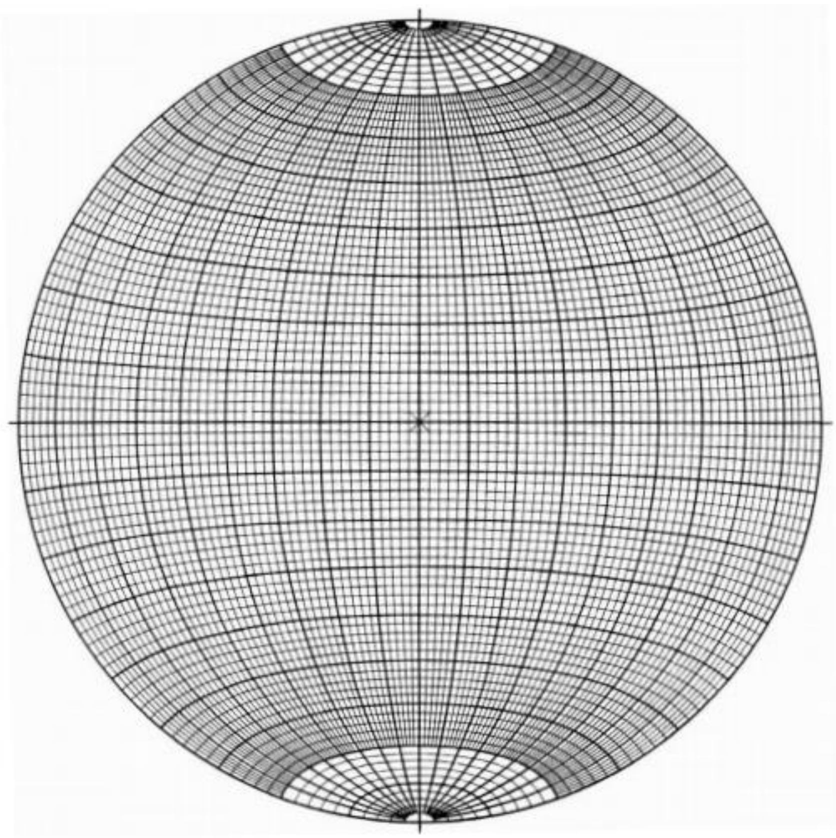
## Task 2.7: H ow to determine the orientation of the fold axis using Pi (π) diagram

A less tedious method of plotting large numbers of attitudes is to plot the poles of a folded surface on the equal-area net. Ideally, in a cylindrical fold these poles will lie on one great circle, called the π-circle. In reality, however, there may be considerable scatter in the distribution of poles and a best-fit π-circle will have to be chosen. The pole to the π-circle is the p-axis, which, like the π-axis, is parallel to the fold axis.




**Problem 2.7:**

The following three foliation attitudes are measured at different places on a folded surface 288, 48 NE, 119, 32 NW, and 176, 47 W. Determine the orientation of the fold axis using π diagram method. (Answer= 31/320)



# ***Week nine***

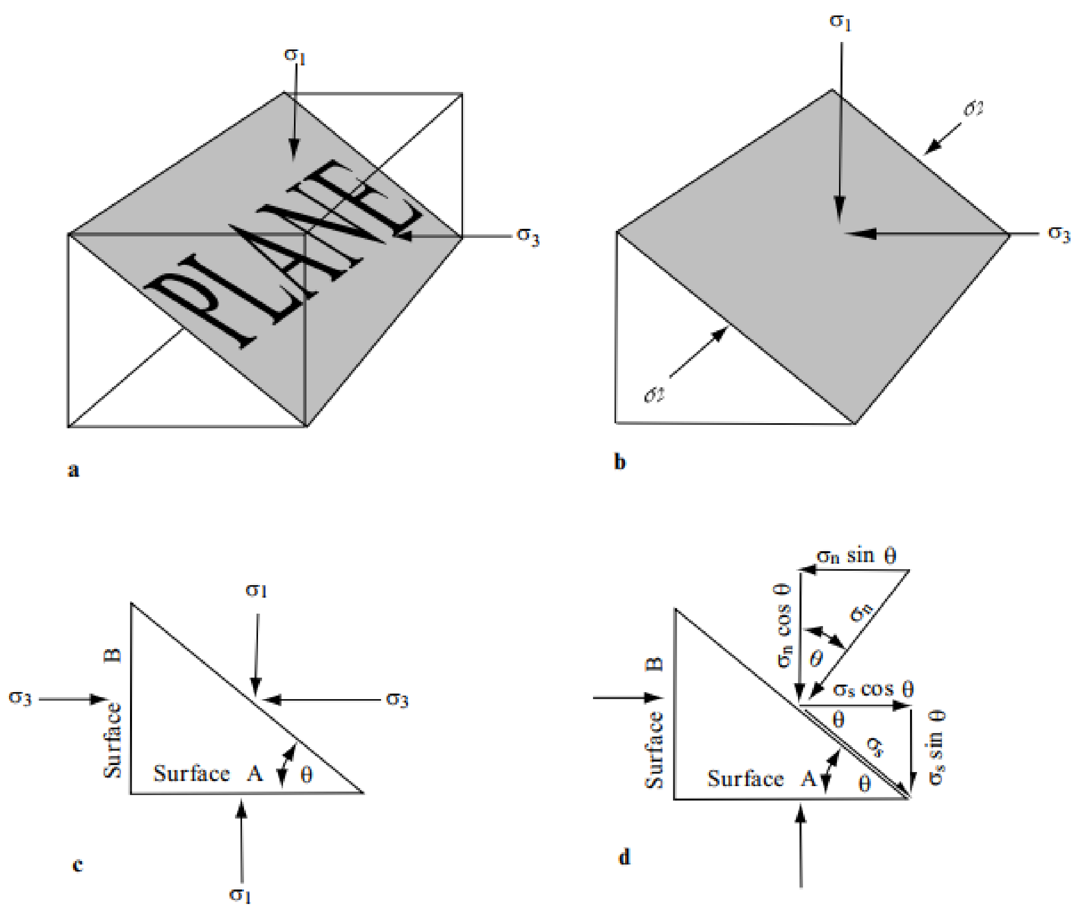
## *Brittle failure (Mohr circle of stress)*

**Objective**

Predict the principal stress magnitudes that will cause a given material to fracture.

Experimental rock fracturing has shown that the difference in magnitude between σ1 and σ3 – called the differential stress – is the most important factor in causing rocks to fracture. The magnitude of σ2 does not play a major role in the initiation of the fracture.

Ө: The angle between the σ3 and the inclined plane.



## Task 1.9: Mathematical methods for determining normal and shear stresses.

$$\sigma_n = \left(\frac{\sigma_1 + \sigma_3}{2}\right) + \left(\frac{\sigma_1 - \sigma_3}{2}\right) \cos 2\theta \qquad \sigma_s = \left(\frac{\sigma_1 - \sigma_3}{2}\right) \sin 2\theta$$

**Problem 1.9:**

1- Given the principal stresses of σ1 equals 100 MPa (vertical) and σ3 equals 20 MPa (horizontal), determine the normal and shear stresses on a fault plane that strikes parallel to σ2 and Ө equals 40.

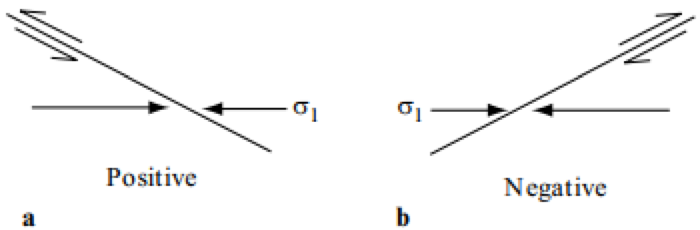
2- Given the principal stresses of σ1 equals 100 MPa (vertical) and σ3 equals 20 MPa (horizontal), determine the normal and shear stresses on a fault plane that strikes parallel to σ2 and dips 32.

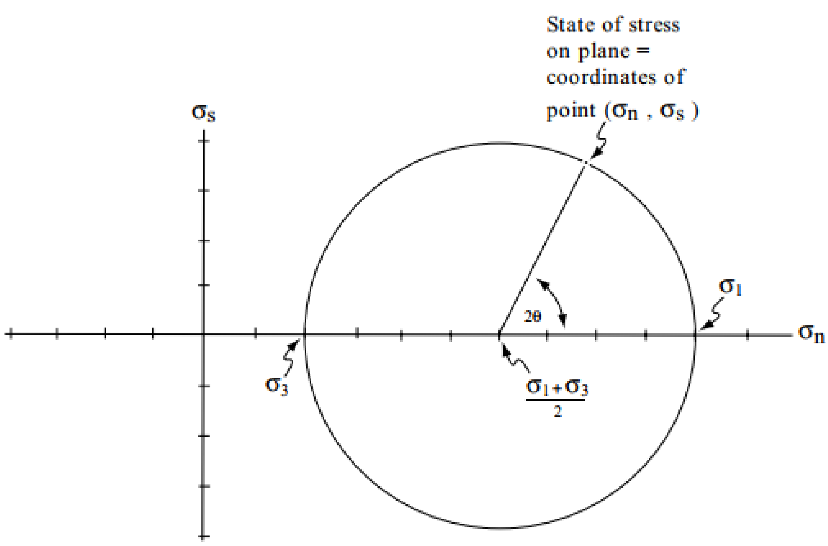
3- Given the principal stresses of σ1 equals 100 MPa (horizontal) and σ3 equals 20 MPa (vertical), determine the normal and shear stresses on a fault plane that strikes parallel to σ2 and dips 32.

## Task 2.9: Graphical methods for determining normal and shear stresses.

In 1882, a German engineer named Otto Mohr developed a very useful technique for graphing the state of stress of differently oriented planes in the same stress field. The stress ($\sigma n$ and $\sigma s$) on a plane plots as a single point, with $\sigma n$ measured on the horizontal axis and ss on the vertical axis. Such a graph is called a Mohr diagram.

Shearing stresses that have a sinistral (counterclockwise) sense are, by convention, considered positive and are plotted above the origin. Dextral (clockwise) shearing stresses are plotted on the lower, negative half of the diagram.




**Problem 2.9:**

1- Given the principal stresses $\sigma1$ is oriented east– west, horizontal, and equal to 40 MPa, while $\sigma3$ is vertical and equal to 20 MPa. We want to find the normal and shear stresses on a fault plane striking north south and dipping 55 west using graphical technique.
2- If $\sigma1$ is vertical and equal to 50 MPa, and $\sigma3$ is horizontal, east–west, and equal to 22 MPa, using a Mohr circle construction determine the normal and shear stresses on a fault striking north–south and dipping 60 east.

# *Week ten*

## *Brittle failure (Failure envelope)*

**Task 10: drawing failure envelope and determining the fracture strength, the angle of internal friction, coulomb coefficient, orientation of fracture plane.**

The Mohr circles at failure under different confining pressures together define a boundary called **the failure envelope** for a particular rock.

**The failure envelope** is an empirically derived characteristic that expresses the combination of $\sigma 1$ and $\sigma 3$ magnitudes that will cause a particular rock.

The failure envelope also allows us to predict **the orientation of the macroscopic fracture plane** that will form when the rock fails.

The angle between this plane and the $\sigma 3$ direction (angle $\Theta$) can be determined by measuring angle $2\Theta$ directly off the Mohr diagram.

**The fracture strength** is the diameter of the Mohr circle ($\sigma a$---$\sigma c$) when the rock fractures.

**The angle of internal friction, ϕ (phi):** The angle between the failure envelope lines and the horizontal axis.

**Coulomb coefficient, μ (mu):** the slope of the failure envelope lines.

$$\mu = \tan \phi$$

**Problem 1.10:**

1- Data from three fracture experiments on identical rock samples recorded in the table below:

| Experiment no | $\sigma c$ Mpa | $\sigma a$ Mpa |
|---|---|---|
| 1 | 40 | 540 |
| 2 | 150 | 800 |
| 3 | 400 | 1400 |

A- Draw Mohr circles for each experiment and draw the failure envelope.
B- Determine the Coulomb coefficient of the sample.
C- Determine the fracture strength for each experiment.
D- Determine the orientation of fracture plane due to $\sigma 3$.

**Problem 2.10:** The results of four fracture experiments on samples of Rohan Tuff are recorded in the table below.

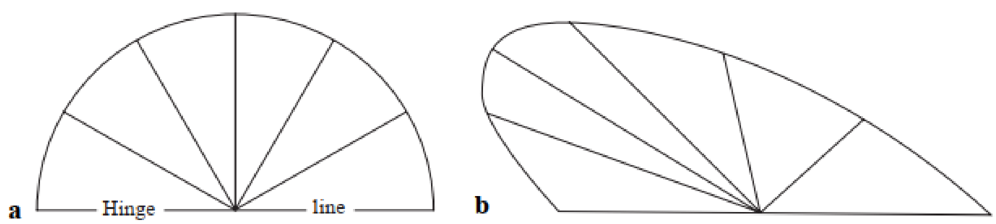
| Experiment no | σc Mpa | σa Mpa |
|---|---|---|
| 1 | 14 | 87 |
| 2 | 42 | 164 |
| 3 | 70 | 242 |
| 4 | 99 | 321 |

1- Draw Mohr circles for each experiment and draw the failure envelope.
2- Determine the Coulomb coefficient of the Rohan Tuff.
3- Determine the angle u that the fracture plane is predicted to form with the s3 direction when a sample of Rohan Tuff fractures.

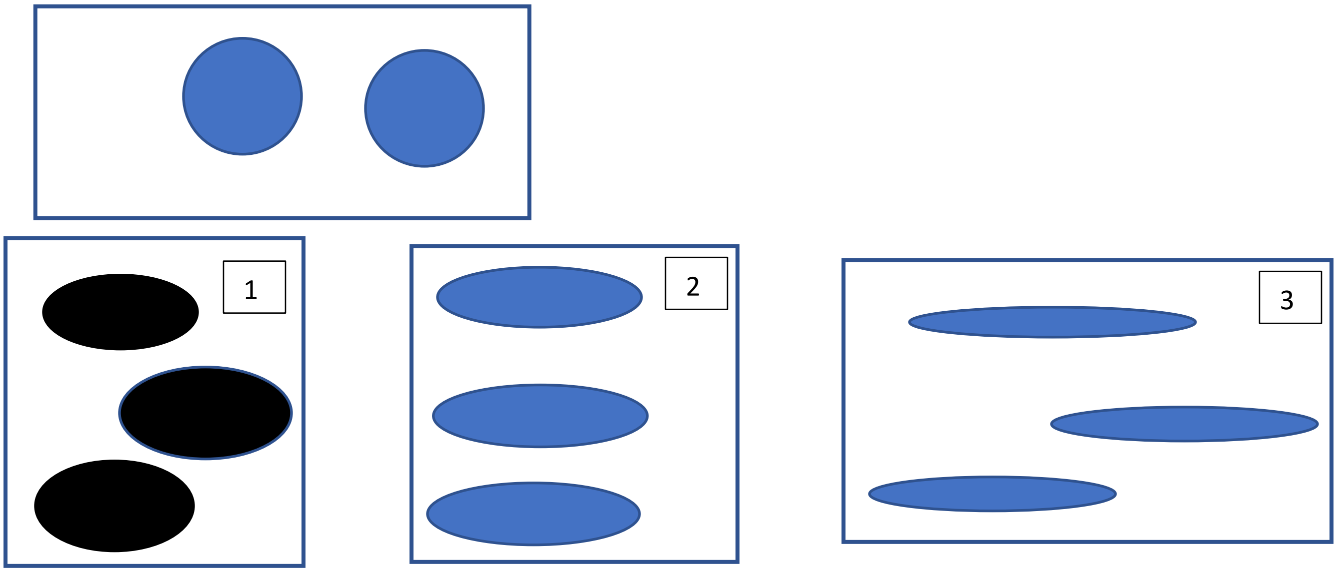
# *Week eleven*

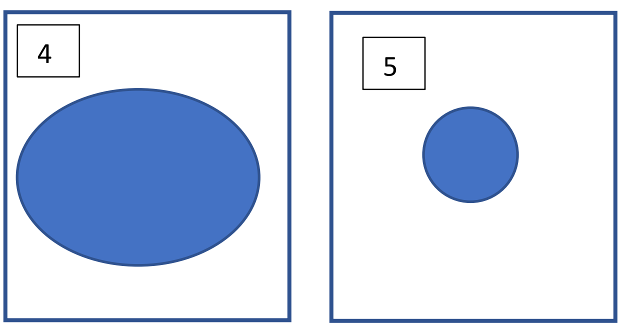
## *Strain measurement (longitudinal and shear strain)*

1) : Diagrammatic brachiopod shell before and after deformation, it's required to
1- Determine the longitudinal strain of the hingeline.
2- Determine the angular shear and shear strain of the shell.




Schematic brachiopod. (a) Undeformed. (b) Deformed. For use in Problem 14.1.




2) On each of the three photographs of the deformed breccia, measure the long and short axis.

1) Calculate the mean for each axis to determine the 1 + e1: 1 + e2 ratio of the strain ellipse.

2) Decide which field the strain ellipse lies in and give your reasons.

## ***Week twelve***

*Kinematic indicators*