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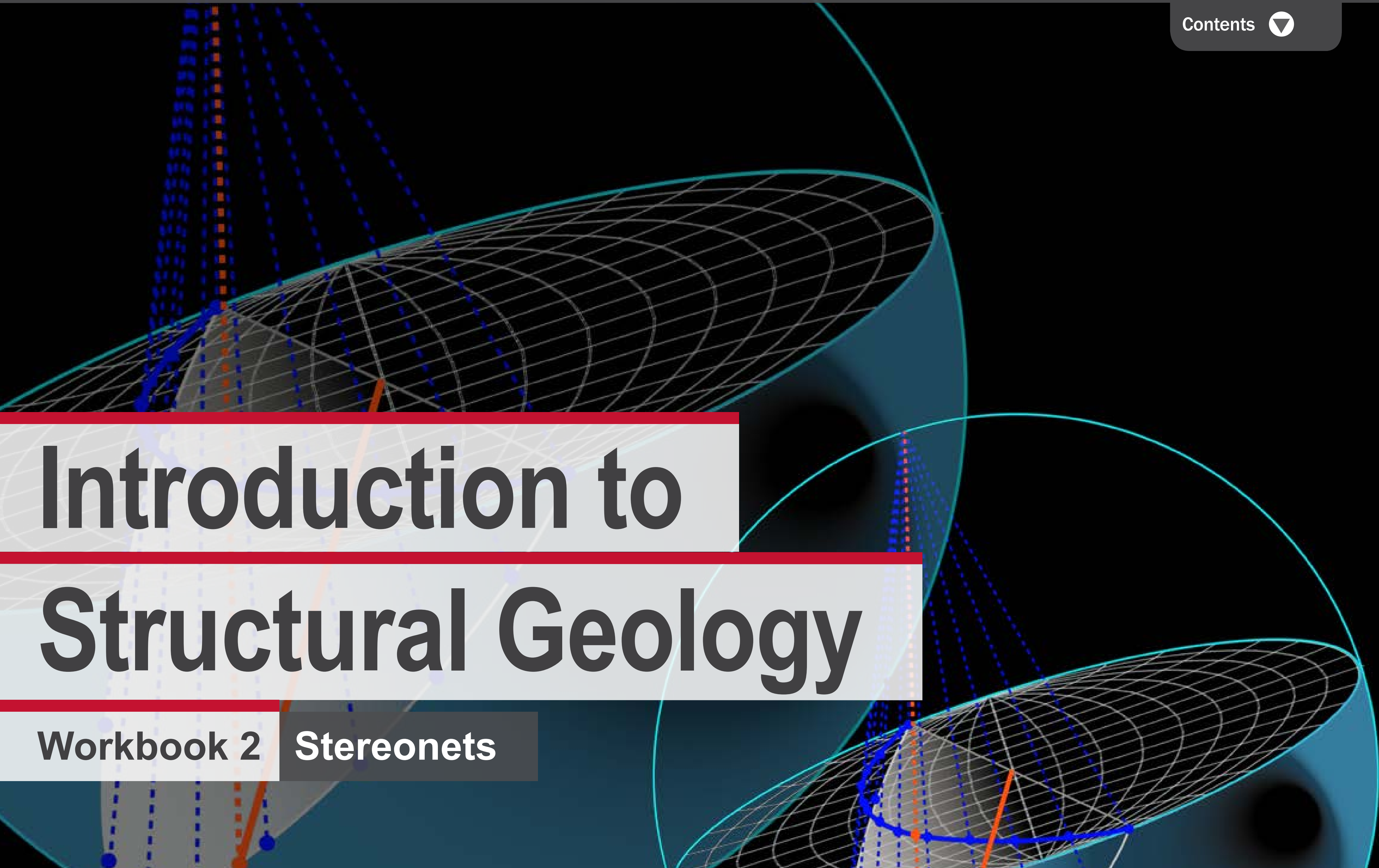
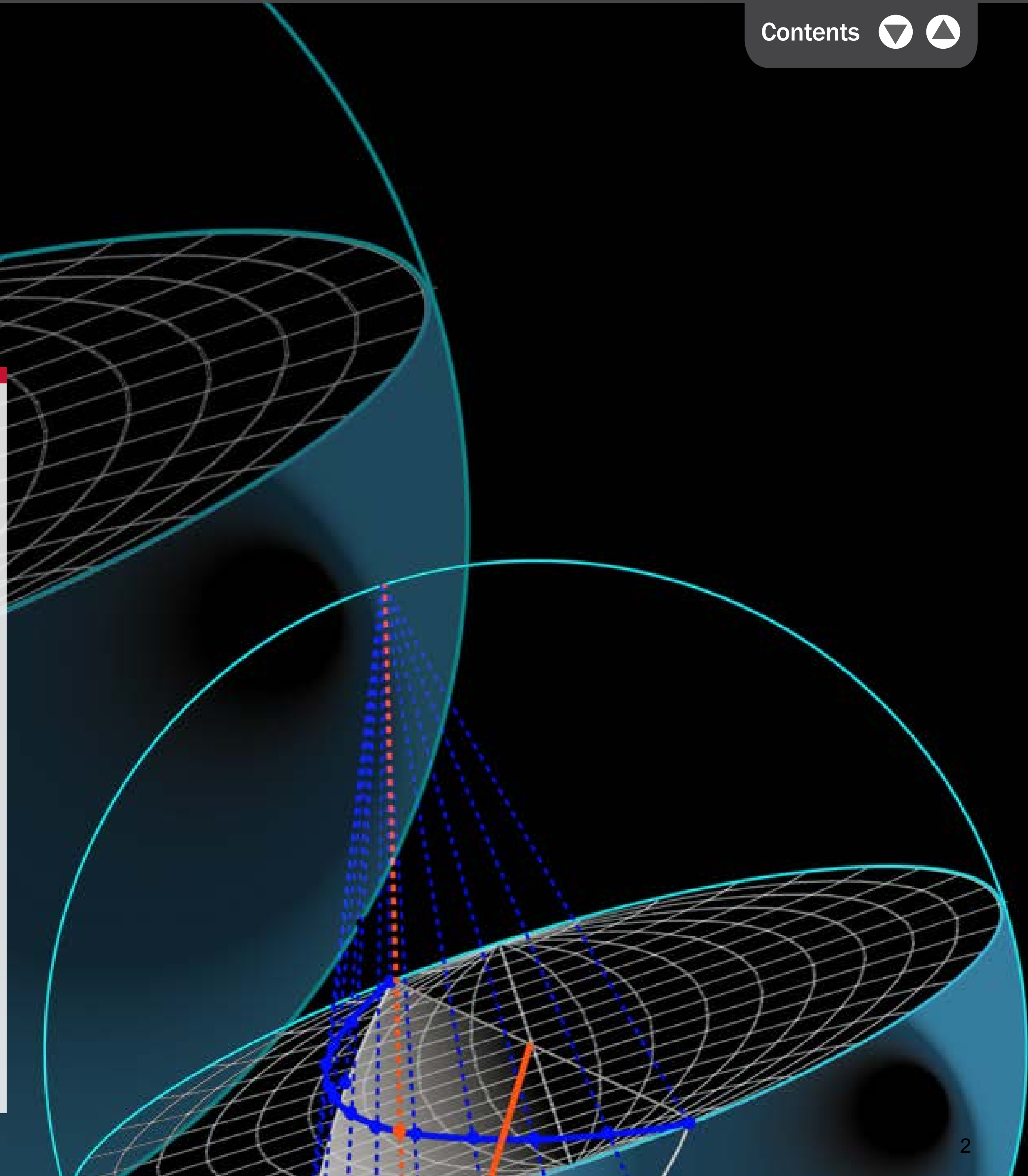


Introduction to Structural Geology

Workbook 2 Stereonets



Contents

How to use this workbook

This worksheet aims to be a general introduction to stereonets that covers basic plotting and some of the more common uses of stereonets in structural geology. By the end of this workbook and associated exercises you should understand what a stereonet is, why they are used in structure geology and be confident in plotting, manipulating and interpreting data on a stereonet.

The worksheet includes basic plotting exercises. Those already confident with plotting data on stereonets may wish to skip these and concentrate on the self-assessment exercises at the end of the workbook. Answers to the plotting exercises can be found by clicking on a reading. The correct answer is shown together with common plotting errors. The stereonet used for the exercises is an equal area stereonet. A blank stereonet is included on a seperate PDF.

Introduction to stereonets

A stereonet is a lower hemisphere graph on to which a variety of geological data can be plotted. Stereonets are used in many different branches of geology and can be used in a range of ways beyond those which are discussed here (see references for further uses). Stereographic projection involves plotting 3D data (planar or linear) on to a 2D surface (stereonet) where it can be manipulated and interpreted.

Imagine a sphere with lines of latitude and longitude marked on it. A stereonet is the plane of projection of the lower half of this sphere – it is a lower hemisphere graph.

Imagine a plane cutting through the centre of a lower hemisphere (figure 1a). The stereonet forms the surface of this lower hemisphere. Looking from above, where the plane touches the edge of the lower hemisphere is an arc. This arc is projected back up on to the stereonet to form a great circle (figure 1b). Figure 1c shows the resulting plot.

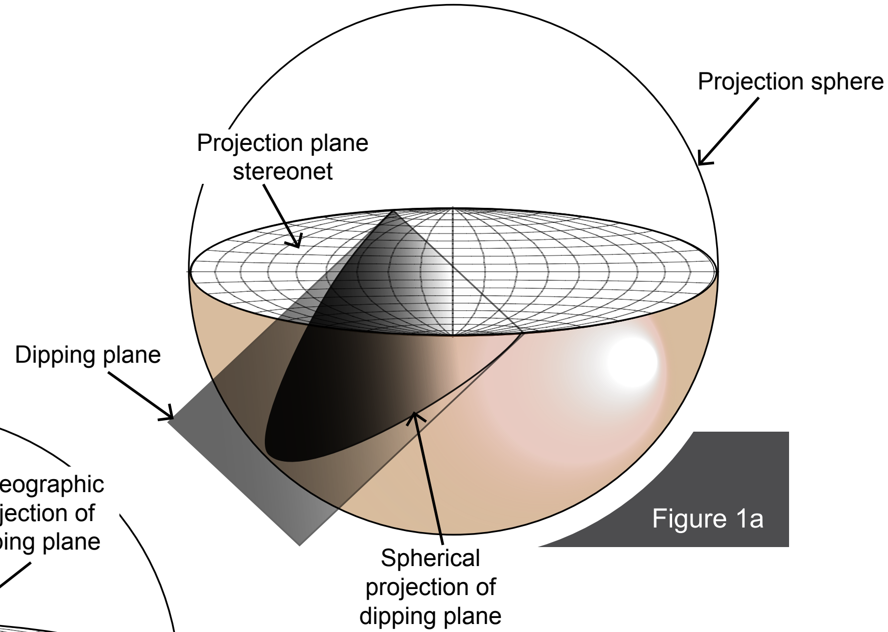


Figure 1a

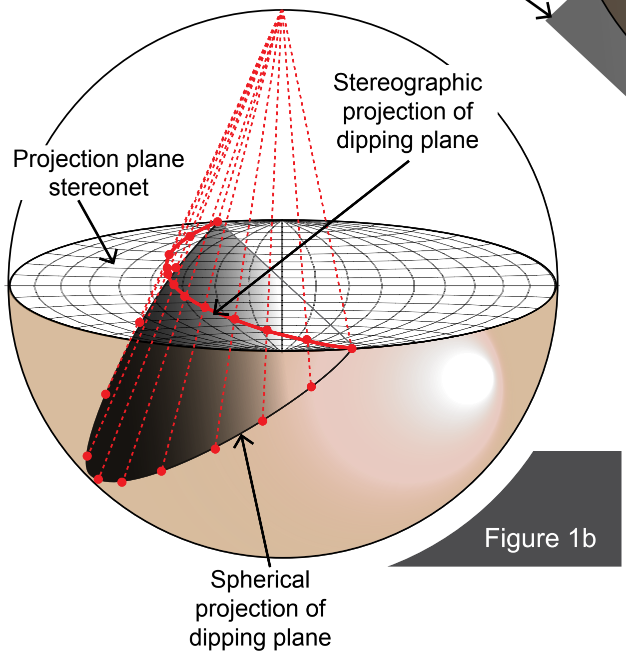


Figure 1b

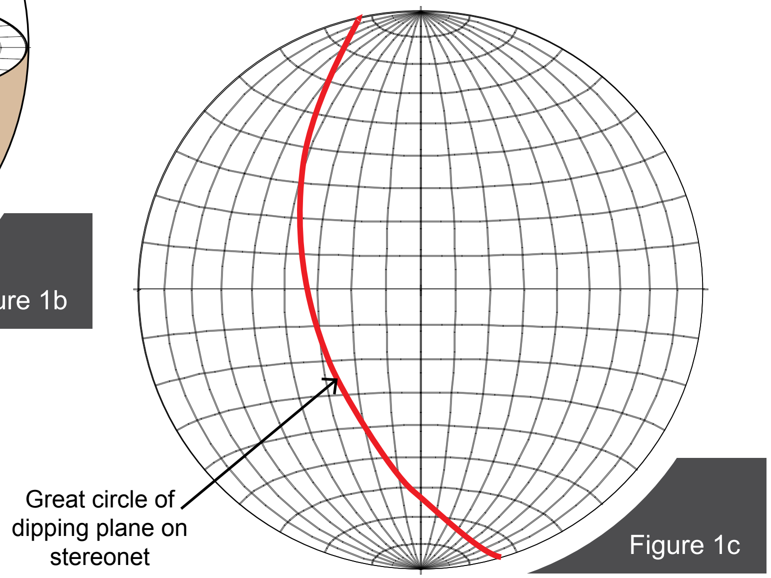


Figure 1c

Figure 2 shows this for a lineation. The lineation lies on the plane (figure 2a), where it touches the edge of the lower hemisphere is a point. This point is projected back up on to the stereonet as a point (figure 2b). Figure 2c shows the resulting plot. Notice how the lineation plots on the great circle of the plane.

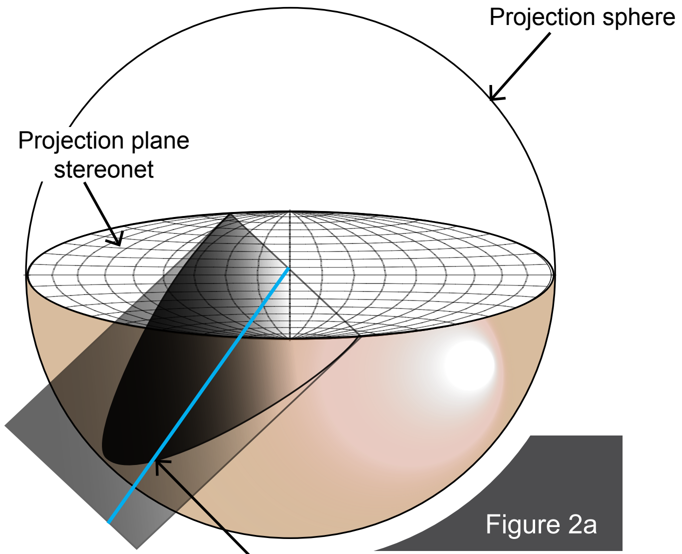


Figure 2a

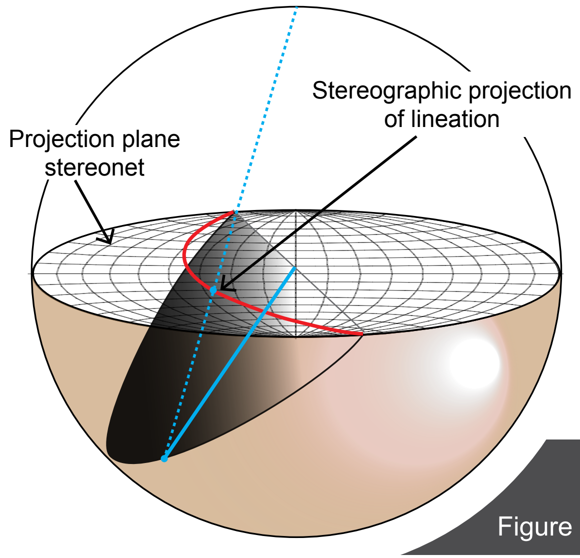


Figure 2b

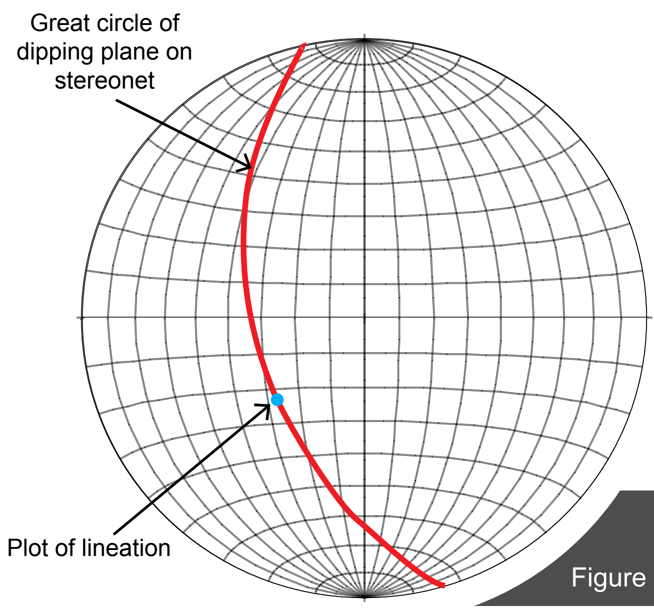


Figure 2c

Planes (e.g. bedding, cleavage, faults etc.) plot as great circles, and lineations (e.g. slickensides, bedding/cleavage lineations, fold axes etc.) plot as points.

In this workbook, all stereonets will be plotted by hand using card stereonets and tracing paper. Why use card stereonets, with tracing paper and drawing pins when data could be input straight into a computer program or a smart phone app?

The obvious reason is one needs to understand the theory behind stereonets to be able to usefully interpret them and to recognise an aberration in the output, which may be due to an input/measurement error. This is best done learning to plot by hand. In the field, for those using notebooks, it is useful to be able to draw a sketch stereonet to test a theory on the geometry of a structure being mapped. Finally, working with stereonets also helps develops 3D thinking, an essential skill in structural geology.

Stereonet terminology

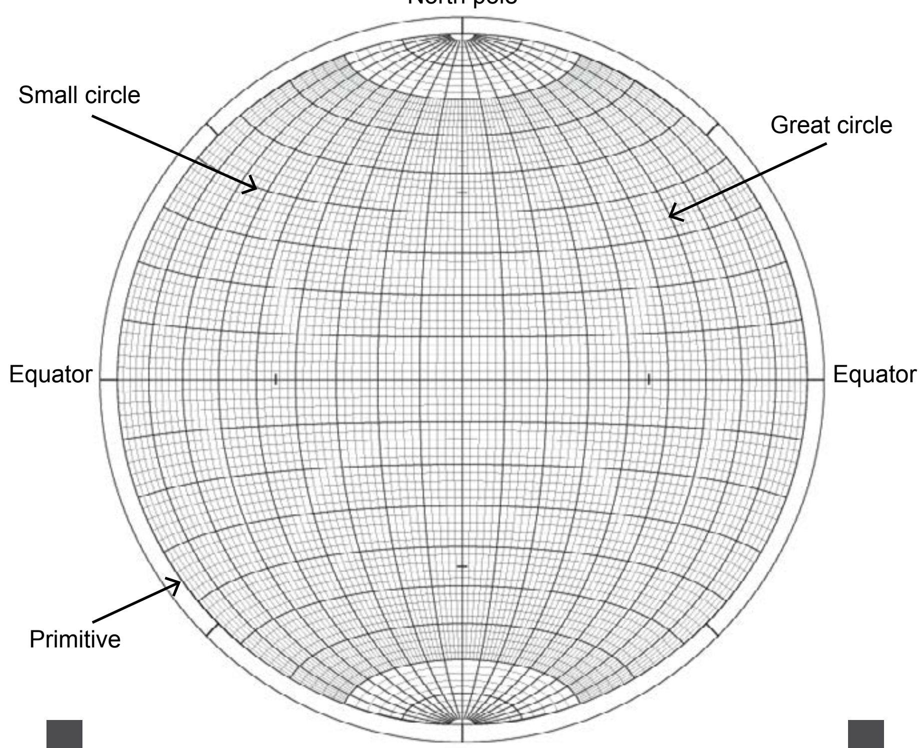


Figure 3: Equal Area Stereonet (Schmidt): each of the sectors has the same area.

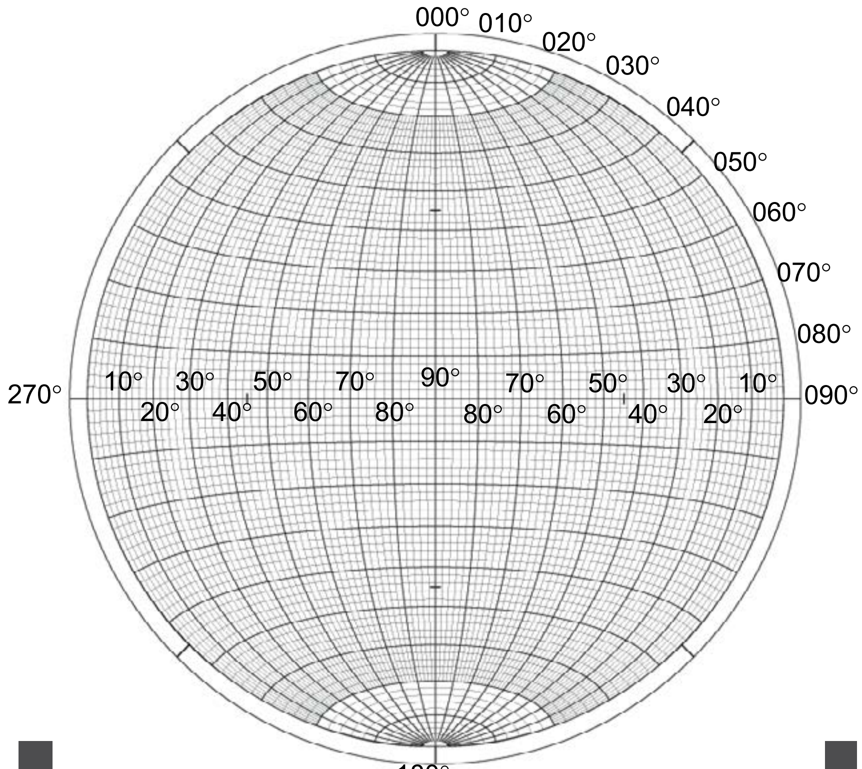


Figure 4: Equal Area Stereonet showing the degrees around the primitive and across the equator.

Figure 3 shows the terminology used to describe the different parts of a stereonet. As a stereonet is a lower hemisphere it is described in a similar way to a globe with north and south poles and an equator across the middle. Great circles are longitudinal, whilst small circles are latitudinal. The primitive is the outside of the stereonet. The stereonet grid is divided into two degree segments with a thicker ten degree lines (figure 4). Strikes and azimuths (bearings) are read around the primitive of the stereonet, dips and plunges are read along the equator.

Setting up a stereonet

Make a hole in the exact centre of the stereonet, by pushing the drawing pin through from the front of the stereonet. Then remove the drawing pin and push it through the hole from the back.

Lay the tracing paper over the stereonet and push the drawing pin through it so that the paper freely rotates round the net

Draw the outline of the stereonet on to the tracing paper. Mark on north, south, east, west or 000°, 090°, 180°, 270° (figure 5).

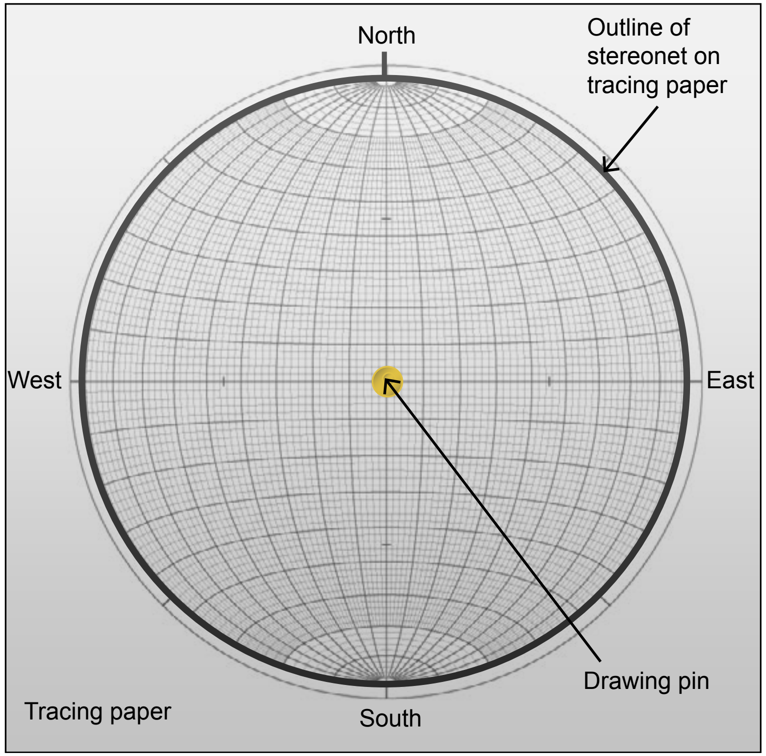


Figure 5: How to set up a stereonet

Click below to watch our YouTube video: How to set up a stereonet

Worksheet 1: Plotting a plane

Planes are measured using strike/dip and dip direction (figure 6) (other methods of measuring are used but this is the convention followed at Leeds and so in the videos, exercises etc). Examples of planes are bedding, faults, cleavage, fold axial planes etc.

Strike: the line of the horizontal on a plane. Measured from north in degrees and recorded as three figures eg. 057

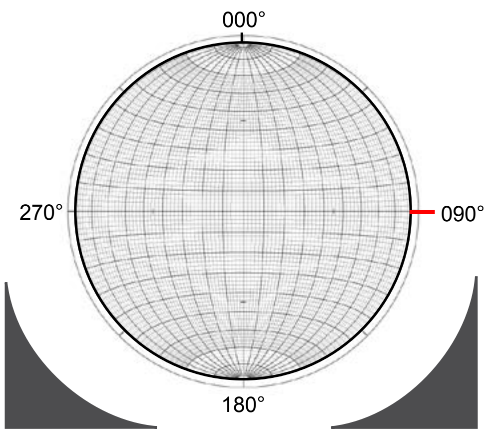
Dip: The maximum dip of a plane. Measured in degrees from the horizontal and recorded as two figures eg. 34. Perpendicular to the strike

Also need dip direction to fully describe the plane eg SE

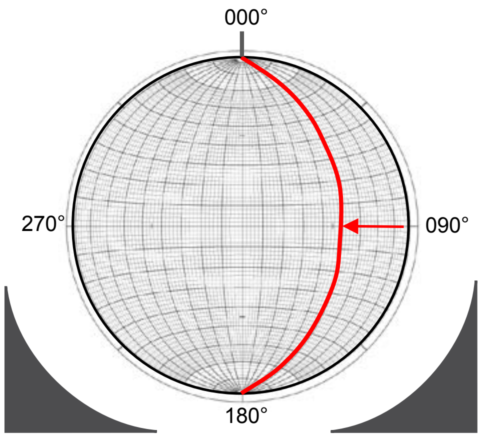
E.g. 057/34SE

Figure 6: Bedding planes dipping towards the road (Miller, 2012).

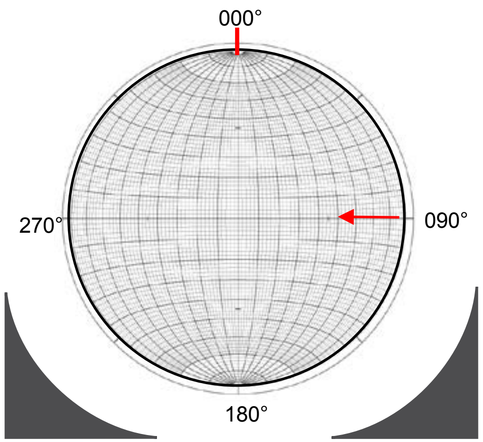
How to plot a plane



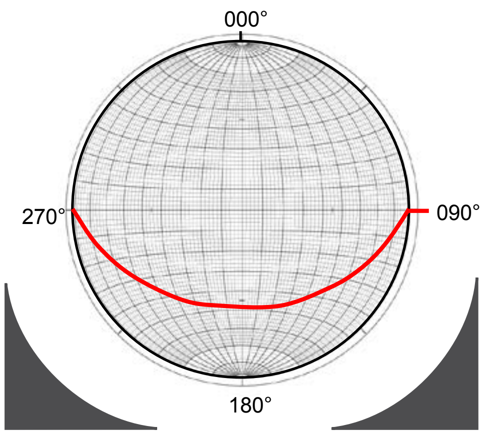
- Strike/dip 090/40S
- Mark on the strike - 090°
- Note which way the plane is dipping, then rotate the tracing paper round until this mark is aligned with north on the stereonet.



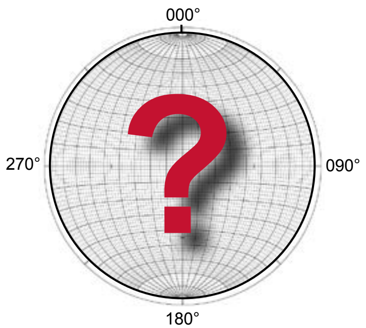
- Using a sharp pencil or colour pencil, draw in the great circle from the north pole through point to the south pole.



- Find the great circle of the plane by counting in the angle of dip along the equator from the primitive. Count in from the direction of dip as marked on the tracing paper (in this case S). Mark with a dot.



- Rotate the tracing paper back to north. Check the plane is dipping in the correct direction and admire your work.



Exercise:

Plotting planes on a stereonet

Plot the following planes on a stereonet

- 032/20NW
- 102/65S
- 177/33E
- 065/82NW

Click on the readings to see the answers

Click below to watch our YouTube video: How to plot a plane

Worksheet 2: Plotting a lineation

Lineations are measured using plunge/ azimuth. Examples of lineations are slickensides and slickenfibres on a fault surface (figure 7), fold axes, mineral stretching lineation or ripple crests.

Plunge: The dip of a lineation as measured from the horizontal. It is measured between 0-90° and always recorded as two figures.

Azimuth: Azimuth is the direction of plunge. It is a bearing and so measured between 0-360° and recorded as three figures.

E.g. a lineation plunging at 45° towards 270° would be written: 45/270

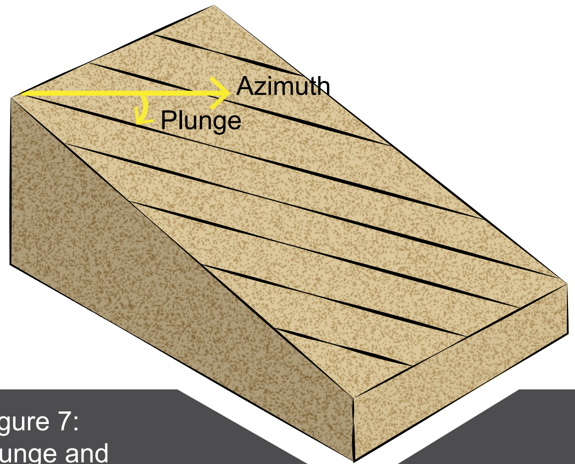


Figure 7:
Plunge and
azimuth of a lineation.

Figure 8: Steeply plunging slickenfibres on a fault plane (J.Houghton).

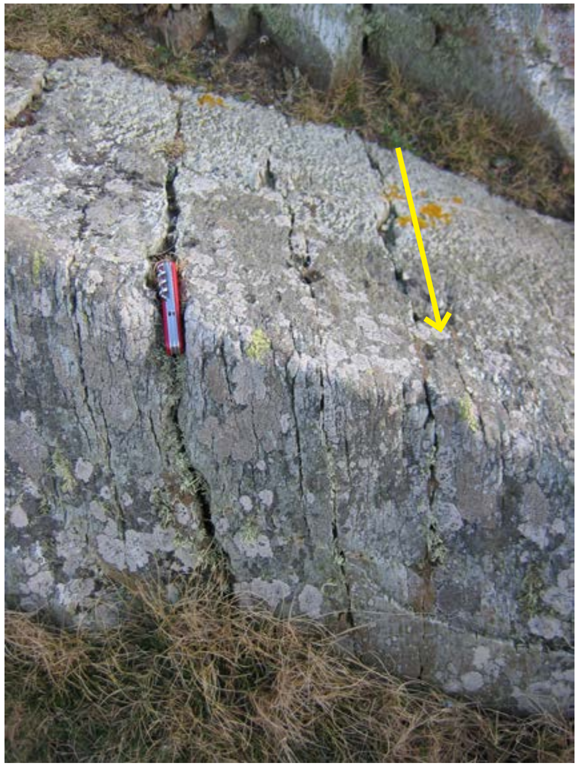
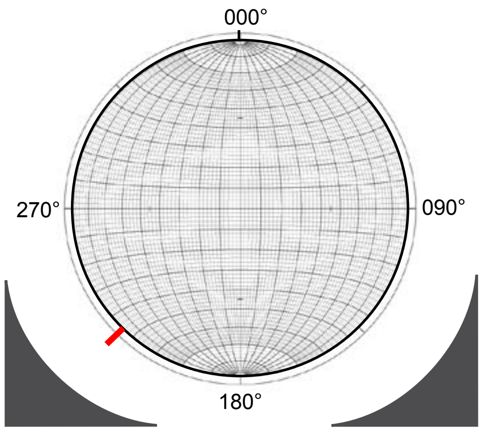


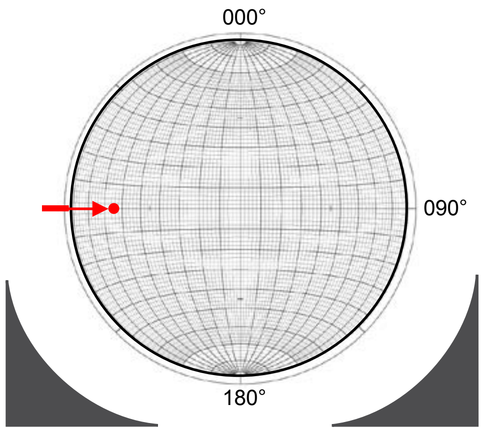
Figure 9: Gently plunging bedding-cleavage lineation (G.Lloyd) See page 14.

How to plot a lineation

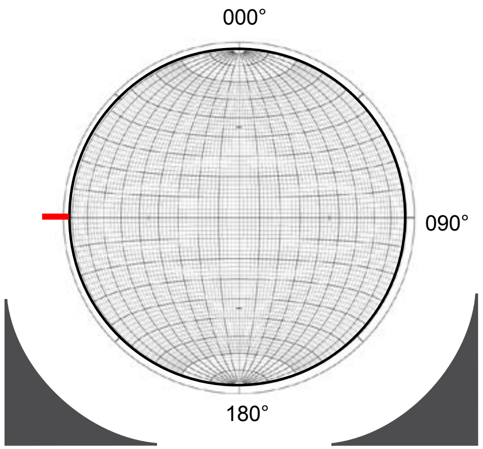


- Plunge and azimuth: 25/225

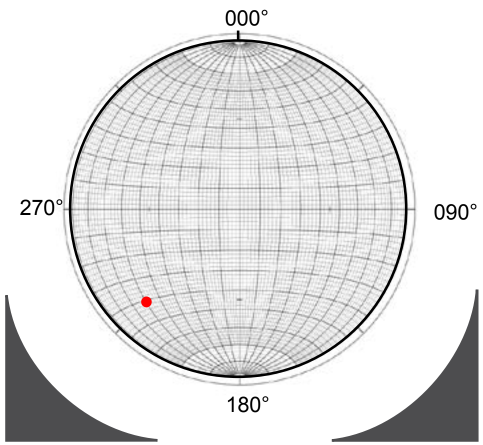
- Mark on the azimuth reading 225°



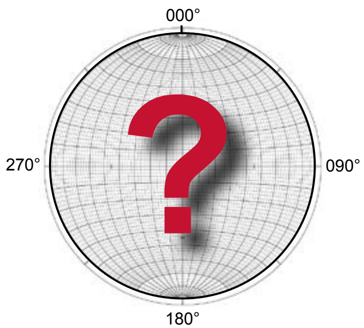
- From the primitive count in the plunge 25°. Mark on the lineation



- Rotate the tracing paper round until this mark is aligned with equator on the stereonet.



- Rotate the tracing paper back and admire your work.



Exercise:

Plotting lineations on a stereonet

Plot the following lineations on a stereonet

- 12/230
- 73/345
- 08/067
- 34/102

Click on the readings to see the answers

Click below to watch our YouTube video: How to plot a lineation

Lineations due to intersection of two planes

Where two planes intersect a lineation is created on one plane where the other plane cuts through it. Figure 10 shows a bedding/cleavage lineation (where cleavage cuts bedding) and a joint/cleavage lineation (where cleavage cuts the joint surface).

On the stereonet the lineation is where the two great circles intersect. Notice how the bedding/cleavage lineation and the joint/cleavage lineation lie on the cleavage plane. Cleavage planes can be difficult to measure in the field, but measuring the lineations on two different surfaces and plotting them on the stereonet allows cleavage to be defined.

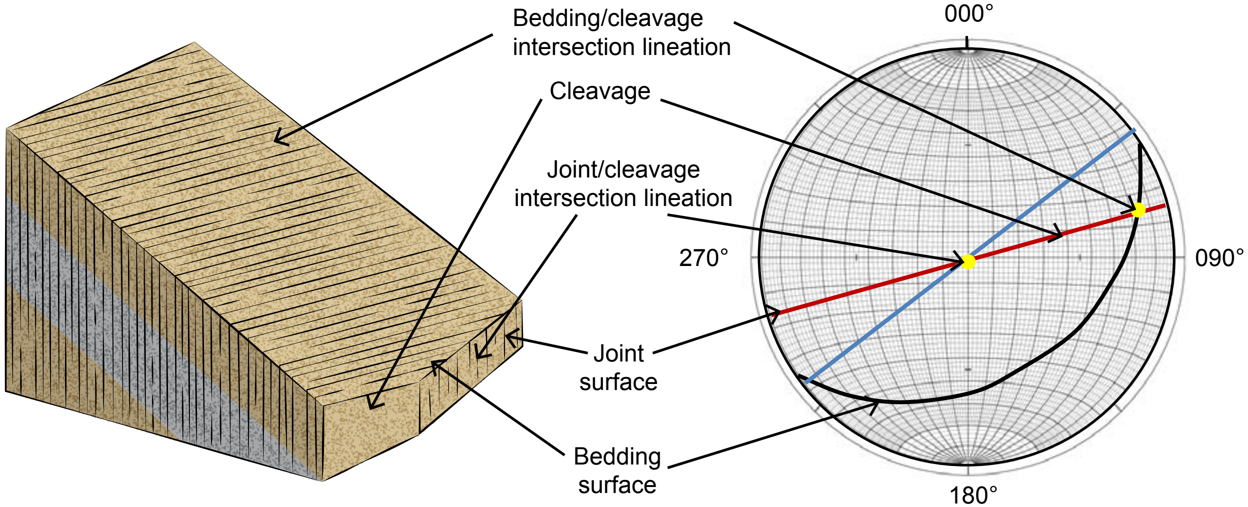


Figure 10: Relationship between three different surface (bedding, cleavage and jointing), their interesections and how this is shown on a stereonet - see text for details

Worksheet 3: Plotting a pole

The pole to a plane is an imaginary line perpendicular to the plane (figure 11).

Poles are quicker to plot, more accurate, take up less space and can reveal patterns more clearly than plotting bedding as great circles.

A stereonet with poles is known as a Pi (π) plot.

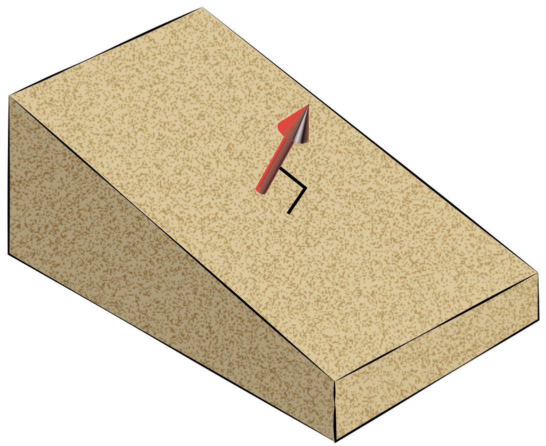
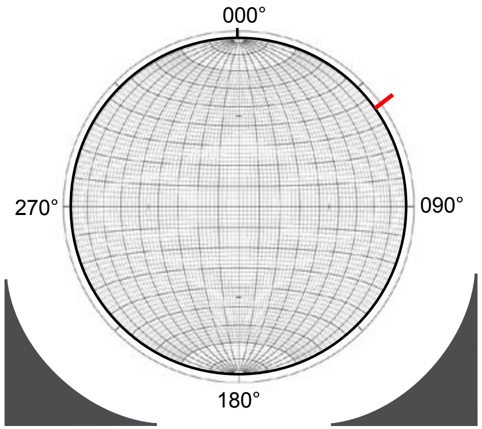
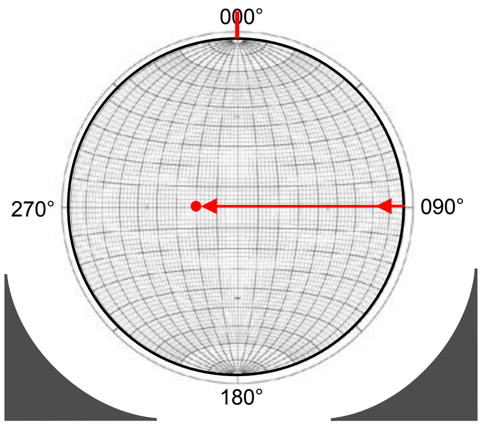


Figure 11: The pole to a plane is an imaginary line perpendicular to that plane.

- Plotting a pole to 055/20 SE





- Mark on the strike reading 055°

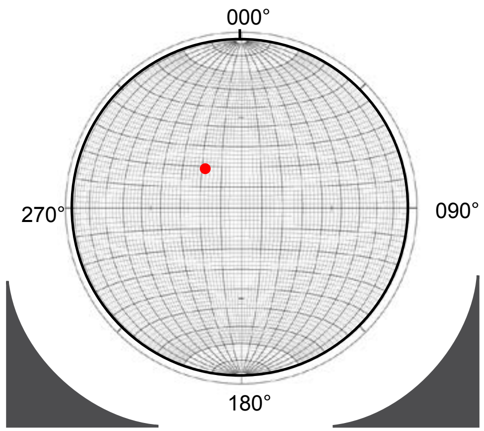
- Note which way the plane is dipping, then rotate the tracing paper round until this mark is aligned with north on the stereonet.

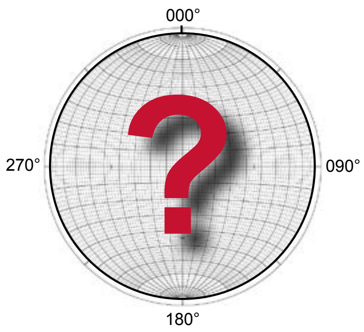
- Find the great circle of the plane by counting along the equator from the primitive. Count in from the direction of dip as marked on the tracing paper (in this case SE) along the equator line 20°.

- Count a further 90° through the centre of the net and mark a point – this is the pole to the plane

- A faster method is to count the dip from the centre of the stereonet along the equator (automatically adds 90°)

- Rotate the tracing paper back and admire your work.





Exercise:

Plotting poles on a stereonet

These are the same readings as in the earlier exercise but here rather than plotting as great circles plot them as poles.

- 032/20NW
- 102/65S
- 177/33E
- 065/82NW

Click on the readings to see the answers

Click below to watch our YouTube video: How to plot a pole

Worksheet 4: Pi-plots and folds on stereonets

Poles are a common way of plotting folded bedding on stereonets. The distribution of poles on the stereonet gives information on the fold's geometry including estimates of the fold axis and the fold axial plane.

Figure 12 shows an upright fold with an axial plane trending north – south. The poles to bedding are distributed in a systematic way. In this simple example the beds all have the same strike, it is only their dip that varies round the fold.

Note how all the beds fall on the same great circle (in this case, along the equator). This will be the same for all cylindrical folds regardless of whether they are upright, inclined, plunging etc., the poles to the folded beds will lie on or close to the same great circle.

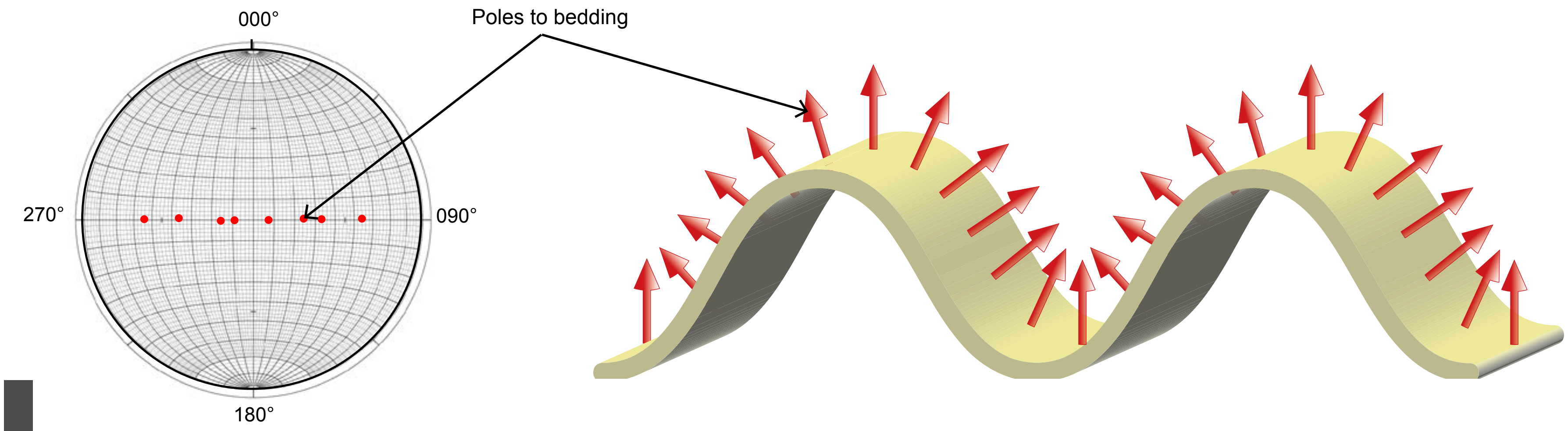


Figure 12: Poles to bedding across a series of folds will plot along the same great circle on a stereonet.

Folds on stereonets

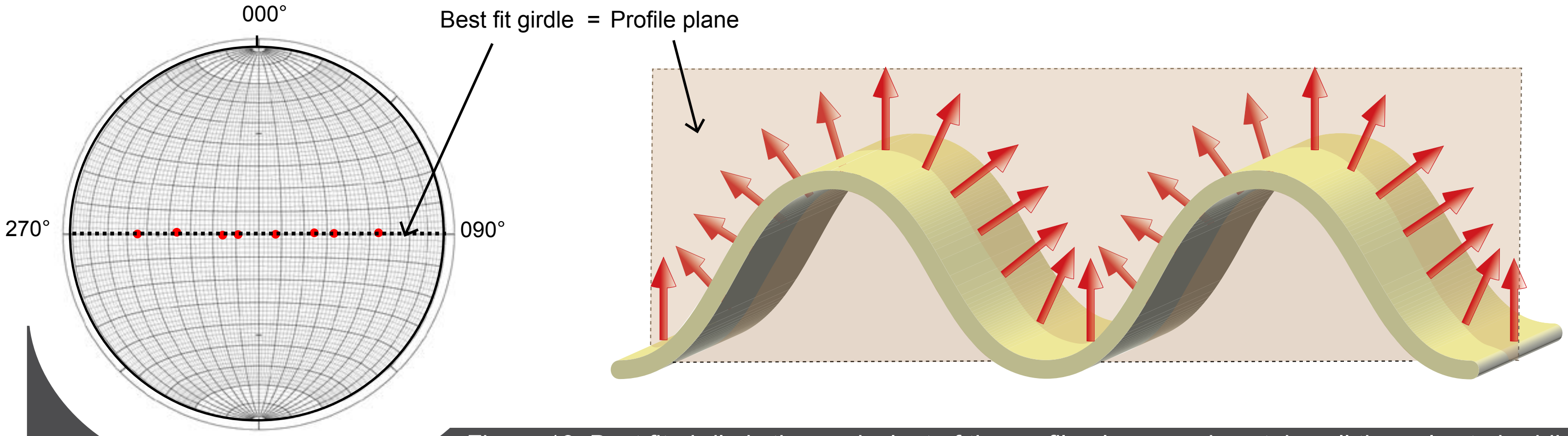


Figure 13: Best fit girdle is the equivalent of the profile planes and contains all the poles to bedding.

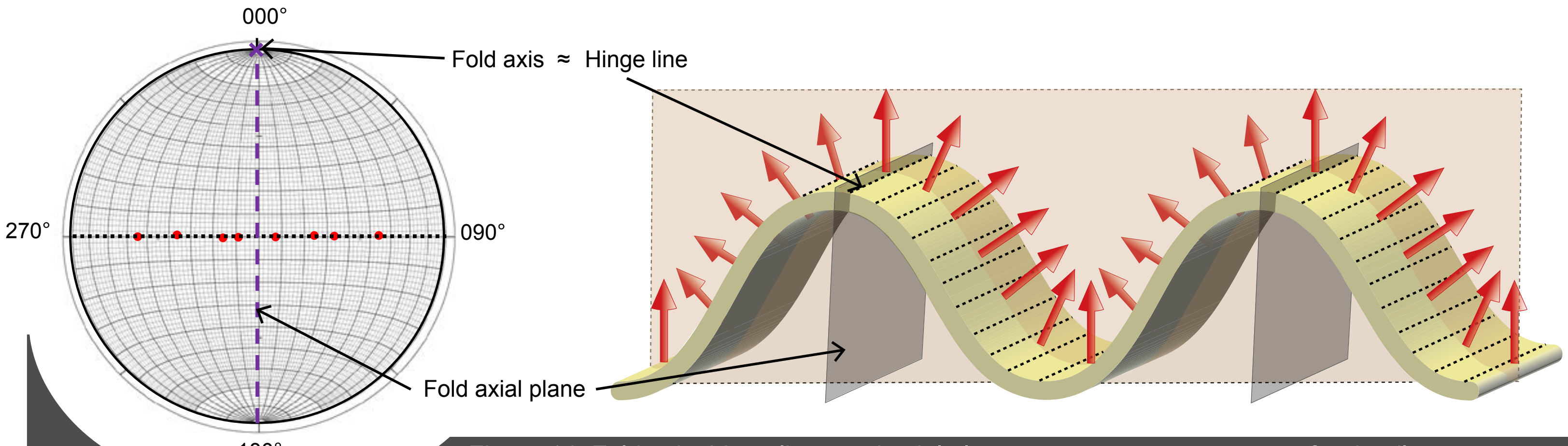


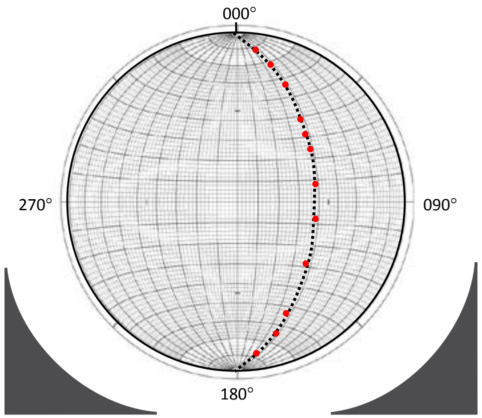
Figure 14: Fold axis, hinge lines and axial planes on stereonets - see text for details.

This great circle on which the poles to bedding lie is known as the best-fit girdle and is the equivalent of the profile plane (figure 13).

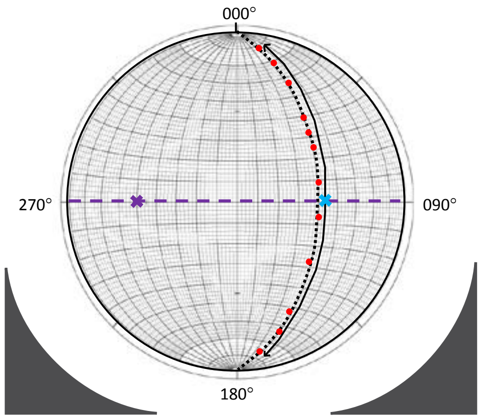
Fold Axes: imaginary lines that lie parallel to the axial plane, normal to the profile plane. These plot as the pole to the profile plane. The hinge line is a fold axis. Fold axes are used to estimate the position of the axial plane (figure 14).

The axial plane goes through the fold axis and bisects the poles to bedding (nb only works where neither fold limb is overturned).

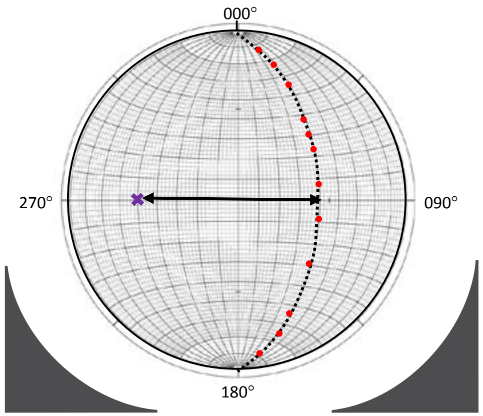
Best-fit great circles, fold axes & axial planes:



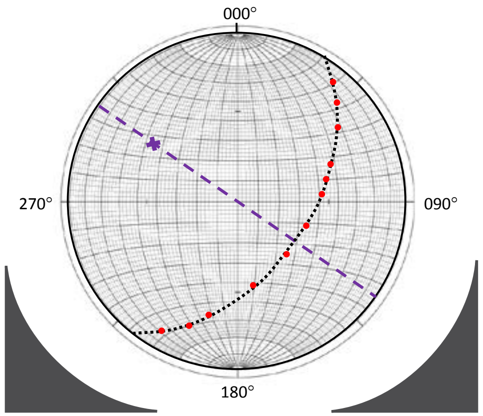
- To find the best-fit great circle plot poles to bedding.
- Rotate poles round to find the great circle the majority lie closest to.
- Draw in the great circle.



- Dividing the spread of the poles gives a second point on axial plane (nb. doesn't work where a limb is overturned).
- Line these two points up with a great-circle and draw in the axial plane.



- Whilst the best-fit great circle is still oriented north – south, mark in its pole. This is the fold axis. It is also one point on the axial plane.



- Rotate the tracing paper back and admire your work.

Relationship between folds and cleavage on stereonets

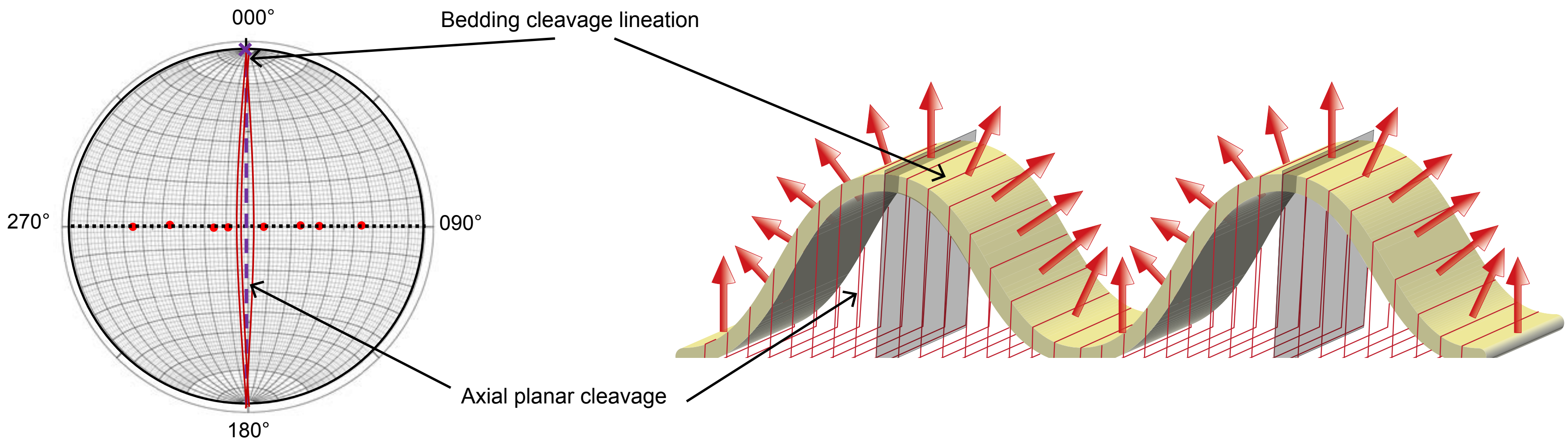


Figure 15: Relationship between axial planar cleavage and fold data on a stereonet.

Both the axial planes of folds and cleavage form perpendicular to sigma one. Where cleavage develops in conjunction with folding, the cleavage will lie parallel to the axial planes. Therefore, the cleavage will plot parallel to the axial plane on the stereonet (figure 15).

The bedding cleavage intersection lineation will lie parallel to the hinge lines of the fold which means these lineations will plot in a cluster close to the fold axes on the stereonet (figure 15).

Different styles of folds on stereonets

The distribution of the poles to bedding around the best fit girdle relates to the interlimb angles of the folds. A gentle fold will only have shallowly dipping beds and therefore the poles to bedding will be concentrated close to the plot of the axial plane (figure 16a). A tight fold has beds with a much wider range of dip from the very steep on the limbs to horizontal in the hinge zone so the poles to bedding will be widely distributed around the best fit girdle (figure 16b). For chevron fold with their straight limbs and sharp hinge zones the poles to bedding will be in two clusters, one for each limb (figure 16c). Inclined folds will have an asymmetric distribution around the best fit great circle reflecting the steeper and shallower dip of the limbs (figure 16d).

The axial planes of upright folds will plot as straight lines great circles on the stereonet, whilst the axial planes of inclined folds will plot as curved great circles.

The best fit girdles of non-plunging folds will plot as straight lines great circles on the stereonet (figure 16a). For plunging folds the best fit girdles will be curved great circles (figure 16b-d).

The fold axes of non-plunging folds will plot on the primitive of the stereonet, whilst the fold axes of plunging folds will plot within the stereonet.

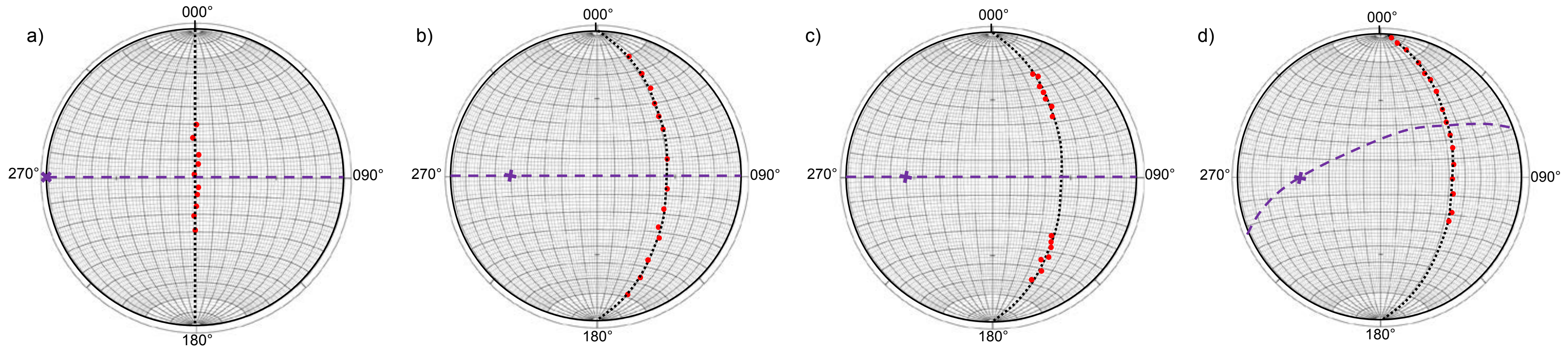
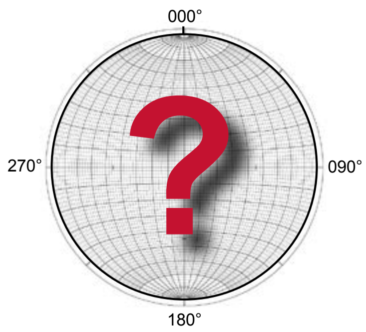


Figure 16: a) Upright, non-plunging gentle fold. b) Upright, plunging, tight fold. c) Upright, plunging, chevron fold. d) Inclined, plunging, tight fold.



For exercises involving the plotting and interpretion of fold and cleavage data on a stereonet see the practical exercises at the end of this workbook.

Click below to watch our YouTube video: Interpreting fold data on stereonets

Worksheet 5: Restorations

It is possible to 'untilt' or restore data to find the original orientation of planes or lineations.

Examples include the original orientation of bedding beneath an unconformity or palaeocurrent data such as cross-bedding, flute casts etc that lie within dipping beds.

Restoring the data involves taking the overlying beds and returning them to the horizontal thus removing the effects of the deformation and allowing the original orientation of the underlying feature to be determined.

For plunging folds this process is done in two stages: first the plunge of the fold axis is returned to horizontal; and second the limbs of the fold are returned to horizontal. This is useful where palaeocurrent indicators are present on folded beds. Removing the effects of the deformation by restoring the beds to horizontal allows the original palaeocurrent direction to be determined.

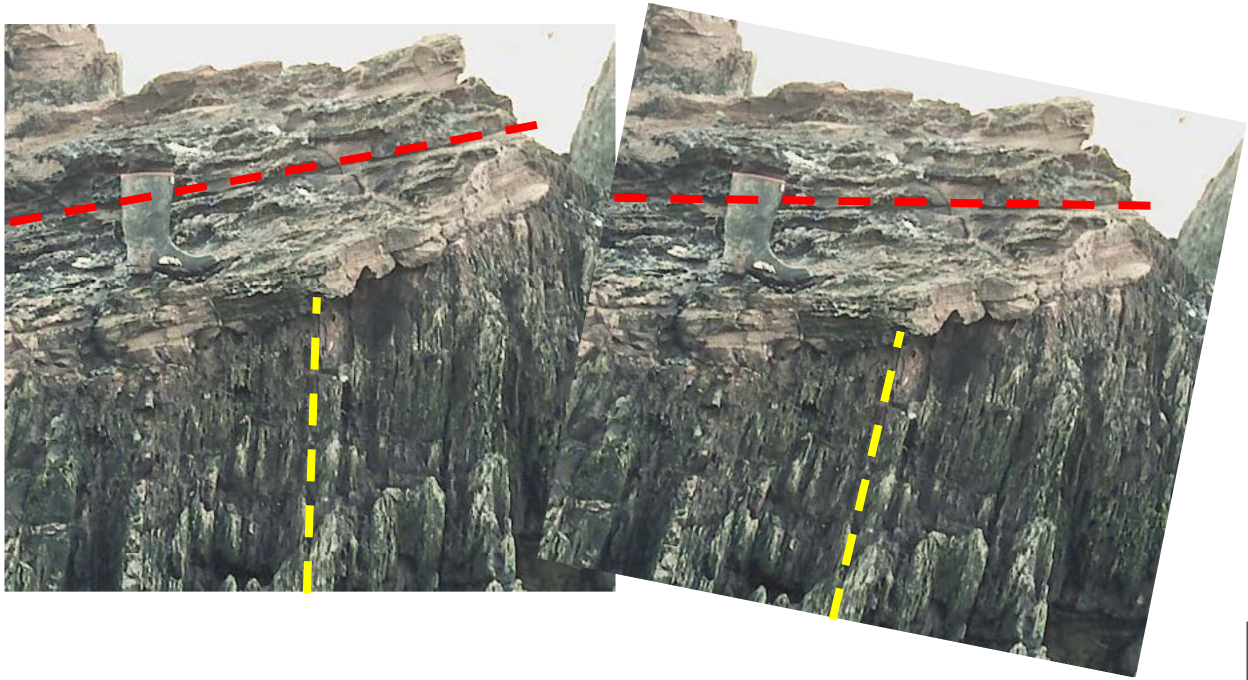
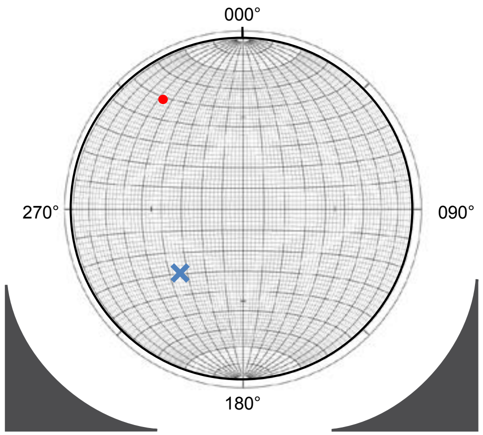


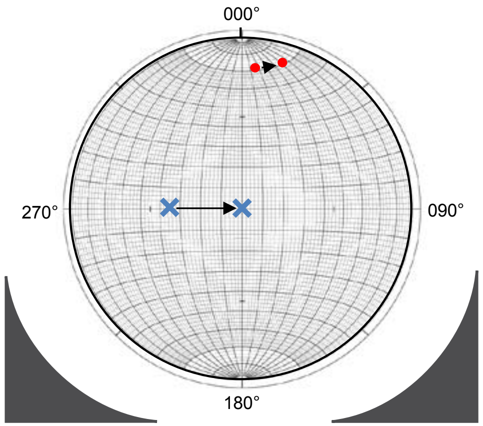
Figure 17: Hutton's Unconformity at Siccar Point where gently dipping Devonian Old Red Sandstone sit unconformably above steeply dipping Silurian greywackes (R.Butler). Rotating the photograph so the red dashed line of the ORS beds returns to horizontal and the yellow dashed line of the Silurian beds dips more to the left illustrates the process of restoring beds on a stereonet.

Restoring a plane



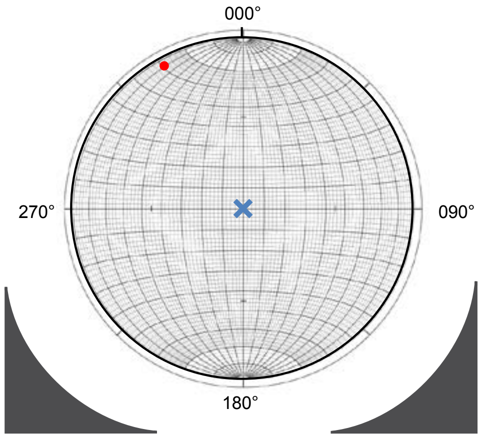
- Plot the poles to bedding above and below the unconformity

- Rotate the pole to bedding above the unconformity to the equator.



- Return this bedding to horizontal by moving its pole along the equator to the centre of the stereonet (the pole is now vertical).

- Move the pole to the bedding below the unconformity along the small circle it is lying on by the same amount. Rotate back to north. This is the position of the pole prior to tilting



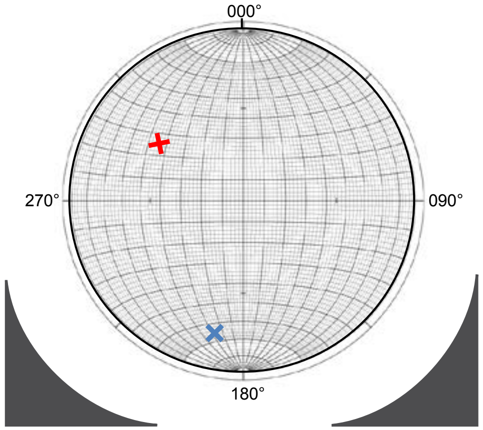
- Read the new orientation of this pole or if you find it easier plot the great circle to the new pole and take the reading from this.

- Original orientation of bedding before later tilting - 058/86SE

× Pole to bedding above the unconformity

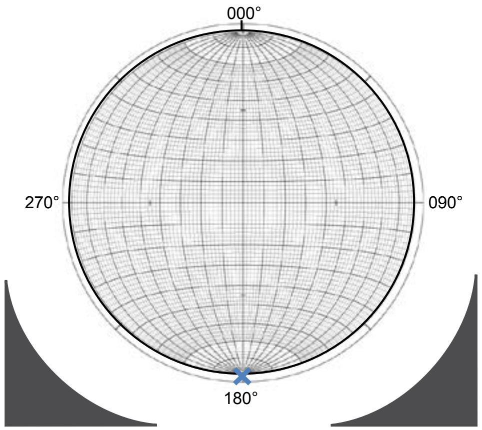
● Pole to bedding beneath the unconformity

Restoring a lineation



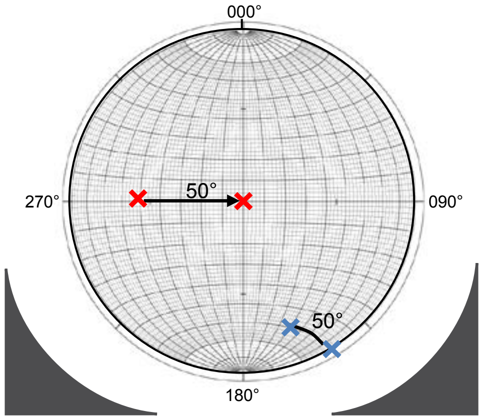
● Plot the pole to bedding and the lineation.

● Rotate the pole to bedding to the equator.



● Rotate the tracing paper back to north and read off the original orientation of the lineation.

● In this case 00/180.



● Return the bedding to horizontal by moving its pole along the equator to the centre of the stereonet .

● Without moving the tracing paper, take the lineation along the small circle it is lying on by the same number of degrees (50° in this case).

Pole to bedding

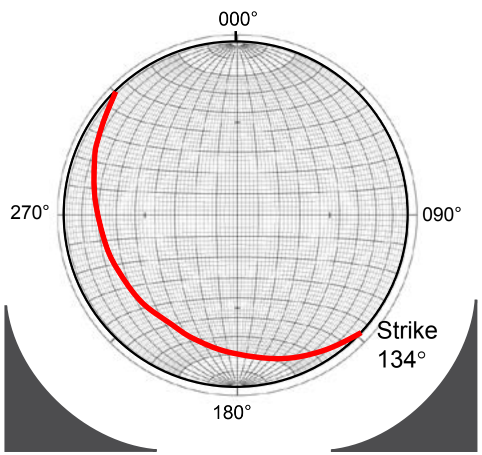
Lineation

Click below to watch our YouTube video: Restoring planes

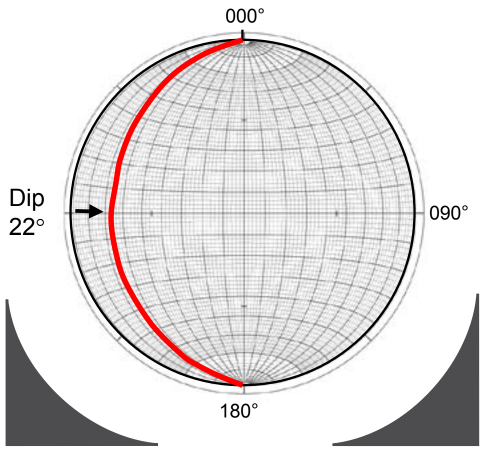
Click below to watch our YouTube video: Restoring lineations

Worksheet 6: Reading measurements from a stereonet

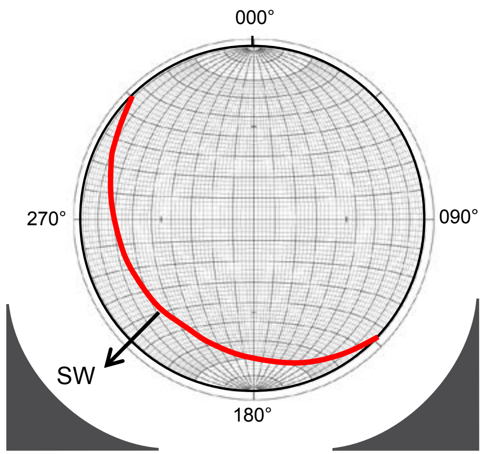
Measuring strike/dip and dip direction of a plane



- Read strike directly from the primitive (outside) of the stereonet: 134°.



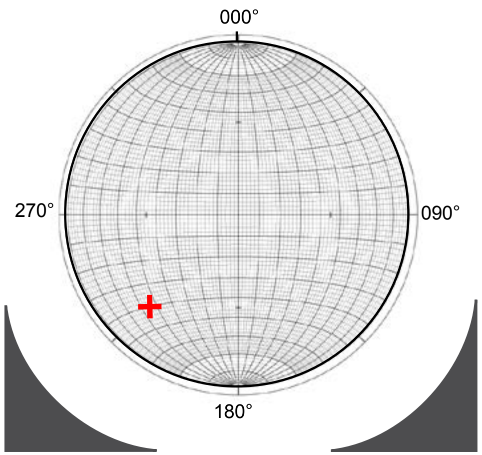
- To measure dip, rotate the great circle to north-south. Count in along the equator: 22°.



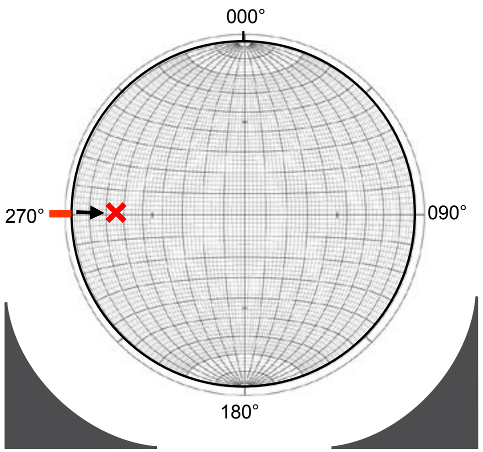
- Rotate the tracing paper back to north. Dip direction is the direction of maximum curvature of the great circle and is recorded as a geographic direction (eg: N, W, SE etc)

- Write as 134/22SW

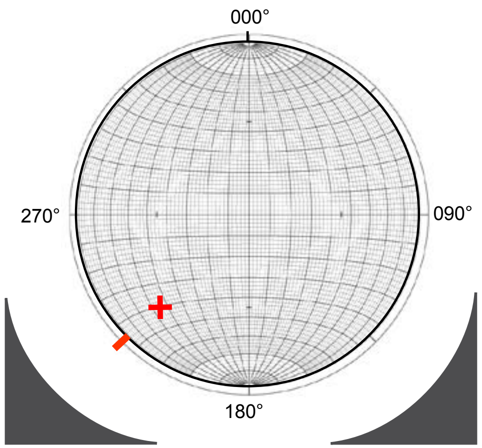
Measuring plunge and azimuth of a lineation



- Rotate the tracing paper round until the lineation is aligned with the equator on the stereonet.



- From the primitive count in along the equator, this gives the plunge: 25°.
- Mark the position of the equator on the tracing paper.



- When the paper is rotated back this marks lies on the azimuth: 225°.
- Write as 25/225.

Practical exercises

Click on the ? for the answers.

Question 1:

A geologist has measured the following bedding and cleavage readings for a sequence of limestones and marls. Plot the poles to bedding and cleavage.

Bedding:

100/10N	170/26E	146/17NE
026/34NW	066/12NW	170/32E
038/20NW	052/15NW	161/19E
033/25NW		

Cleavage:

110/80N	114/88N	116/81N
117/87NE		

- What is the plunge/azimuth of the fold axis?
- What is the strike and dip the fold axial plane?
- What is the geometry of folds?
- Did the cleavage form at the same time as the folding? Give reasons for your answer.

?

Question 2:

A geologist has measured the following bedding and cleavage readings for a sequence of psammite and semipelites.

Bedding	Cleavage
168/32W	024/82NW
116/20SW	031/86SE
052/44SE	026/90
002/48W	028/87SE

- What is the plunge/azimuth of the bedding/cleavage lineation?
- What is the plunge/azimuth of the fold axis?
- How does this compare with the bedding/cleavage lineation?

Plot the following minor fold hinge lines:

14/203	26/210	29/205	16/208

- Where these minor folds formed in the same stress field as the cleavage?
- Give reasons for your answer.

?

Question 3:

A bed on the western limb of the syncline dips at 150/20NE and within it has cross bedding at 100/38N. The same bed on the eastern limb of the syncline dips at 050/40NW and within it has cross bedding at 052/64NW. Do a two stage restoratioin of the fold - first correct for the plunge of the fold by bringing the fold axis up to horizontal and then restore each limb to horizontal.

- What was the original migration direction indicated by each of the cross-bedded units?

Western limb:

Eastern limb:

- Do these readings suggest a broadly similar migration direction?

?

Question 4:

A cleavage/bedding intersection lineation of 30/164 is observed on a bedding plane orientated at 080/30E. The same cleavage forms an intersection lineation 66/012 on a vertical joint surface that trends 012.

- What is the orientation of the cleavage?

Question 5:

Mapping along the coast a geologist comes across an area with good exposure in the cliff face and on the foreshore. Interbedded psammites and pelites (metamorphosed sandstones and shales) have been folded, faulted and intruded by a series of igneous dykes.

Plot up the following readings over as many stereonets as you think necessary. Plot the planes (bedding, cleavage, faults and dykes) as poles or great circles as you think appropriate.

Bedding:

152/28SW	125/66SW	040/15NW
138/40SW	121/84SW	079/23N
170/18W	127/60SW	

Bedding with flutes (plunge and azimuth)

152/28SW	22/201
127/60SW	59/205
170/18W	11/209

Cleavage:

106/50NE	113/52NE	105/56NE
112/51NE		

Faults and slickensides (plunge and azimuth):

106/55SW	55/189
110/60SW	60/194
101/64SW	64/182
104/60NE	60/007

Dykes:

110/84SW	106/88NE	108/90

- What is the plunge/azimuth of the fold axis?
- What is the strike/dip of the fold axial plane?
- What is the geometry of folds?
- How does the cleavage relate to the fold?
- What type of faults are they and what sense of movement do the slickensides indicate?
- Give the direction of sigma 3 during the formation of the faults:
- In approximately which direction was the palaeocurrent flowing as given by the restored flute marks?
- Give the direction of sigma 3 during the intrusion of the dykes:
- Were the dykes, folds, faults and cleavage all formed under the same stress field? If not, which set of structures came first?
- From all the information available write a detailed geological history.

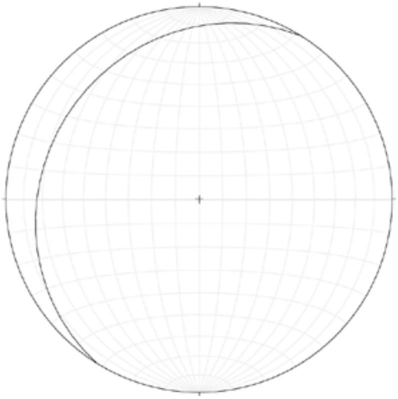
Exercise answers

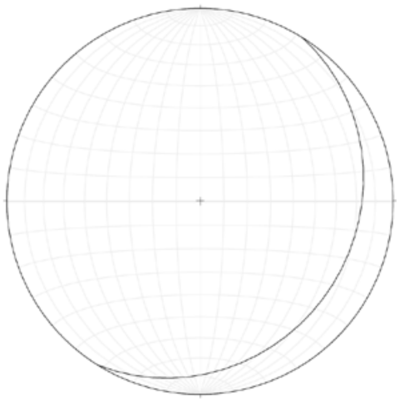
Exercise 1: Plotting planes

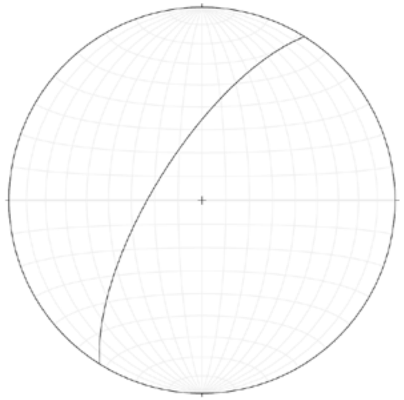
Back to questions

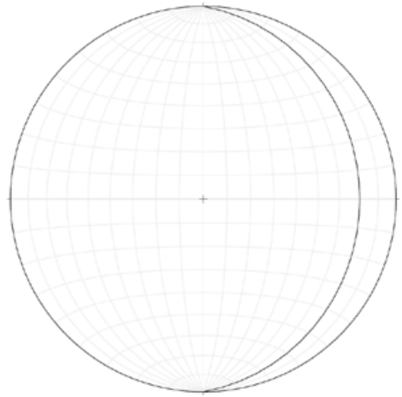
032/20NW

Correct









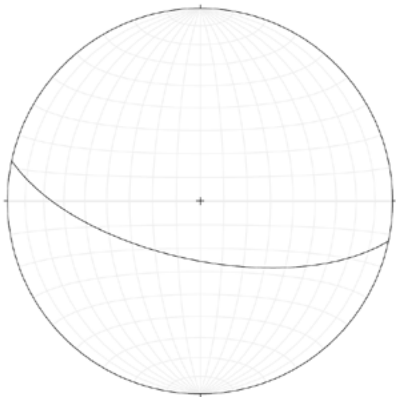
102/65S

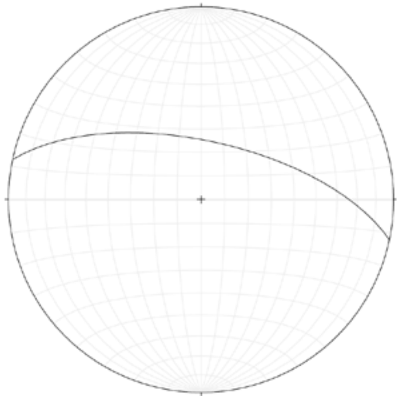
Correct

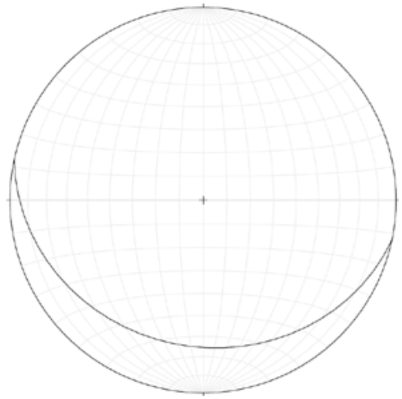
Counted the dip in from the wrong side of the stereonet

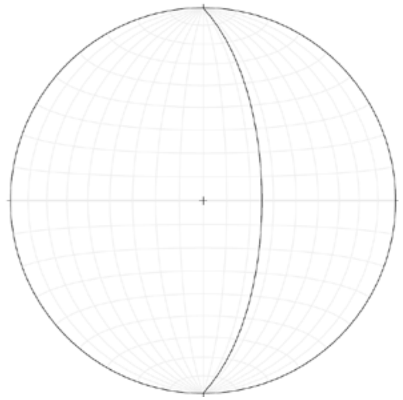
Counted dip from the centre of the stereonet not the outside

Just measured dip and not strike







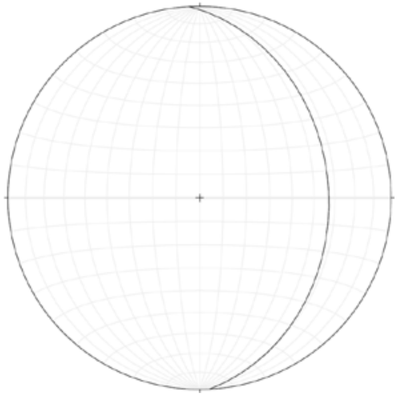


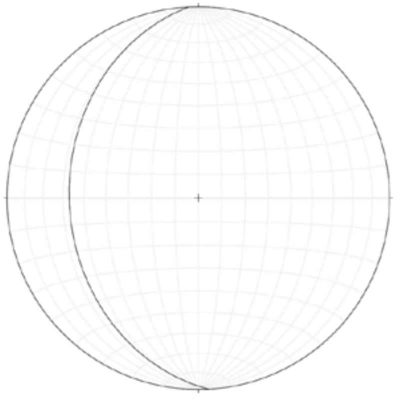
Exercise 1: Plotting planes

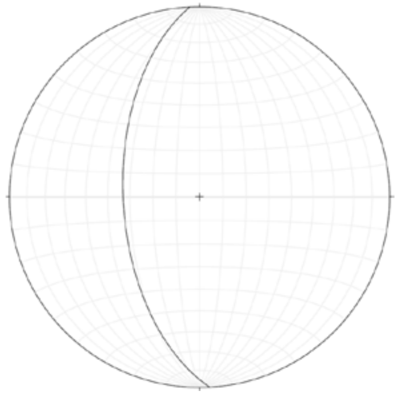
Back to questions

177/33E

Correct







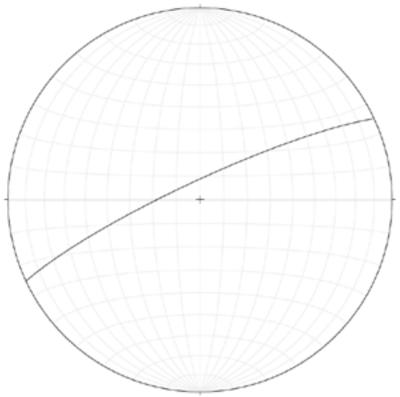
065/82NW

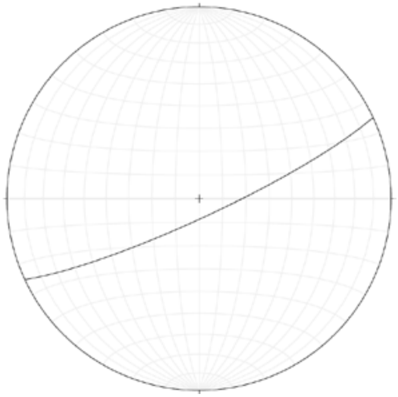
Correct

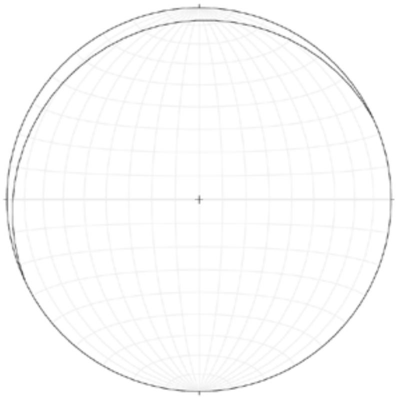
Counted the dip in from the wrong side of the stereonet

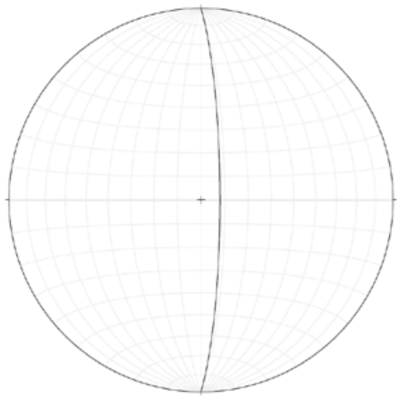
Counted dip from the centre of the stereonet not the outside

Just measured dip and not strike





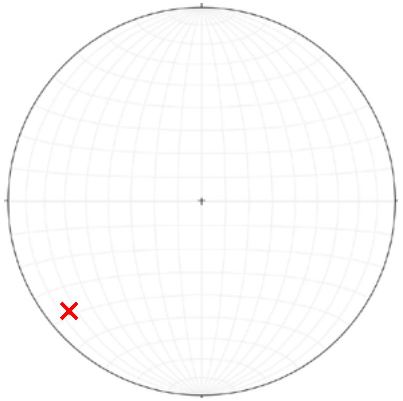


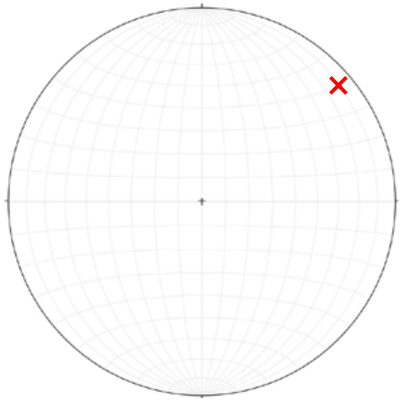


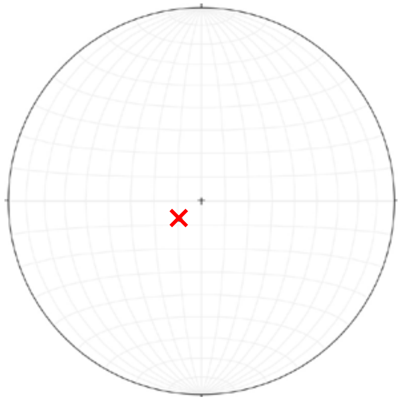
Exercise 2: Plotting lineations

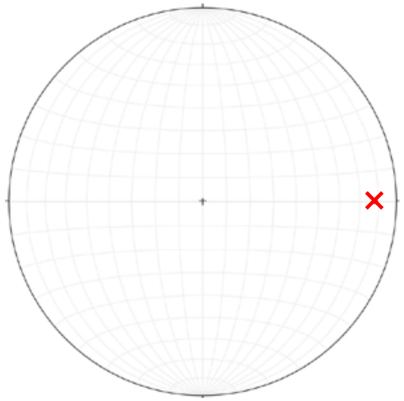
Back to questions

12/230
Correct







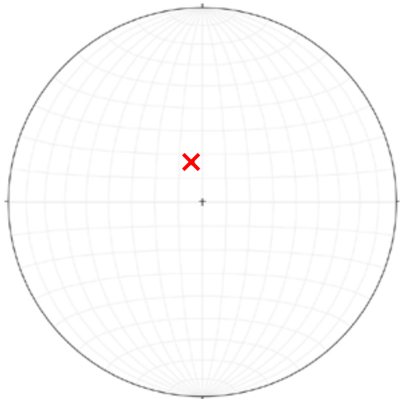


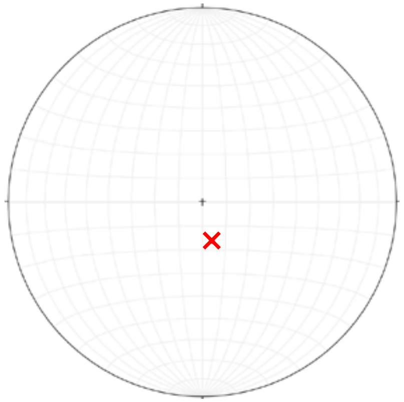
73/345
Correct

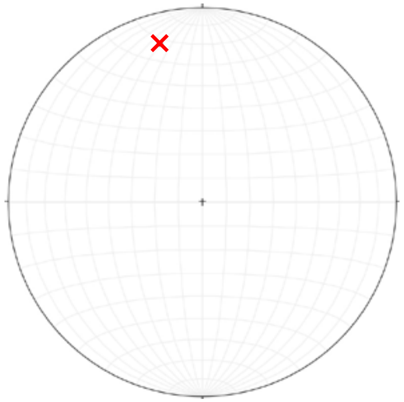
Counted in from the wrong side of the stereonet

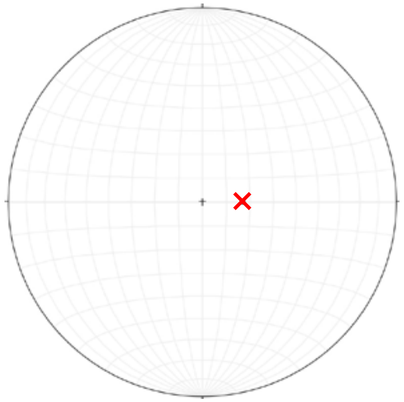
Measured from the centre of the stereonet not the outside

Just measured plunge not azimuth







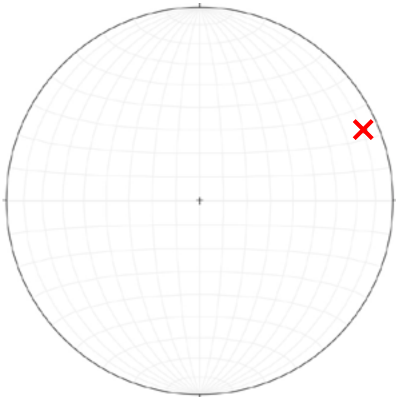


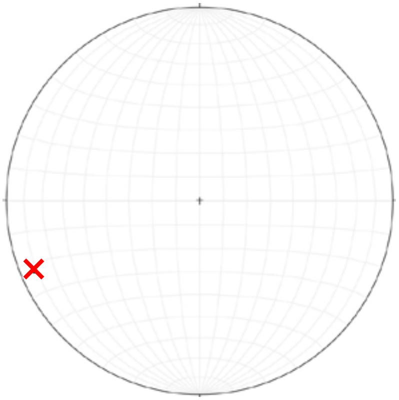
Exercise 2: Plotting lineations

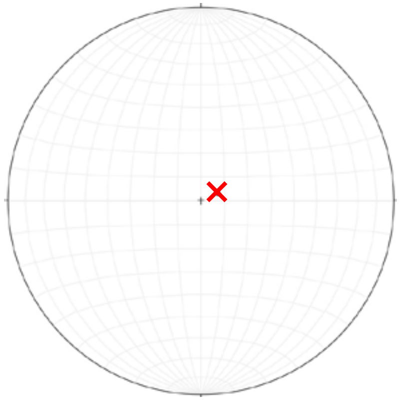
Back to questions

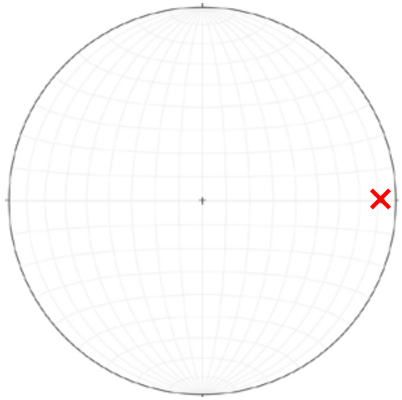
08/067

Correct









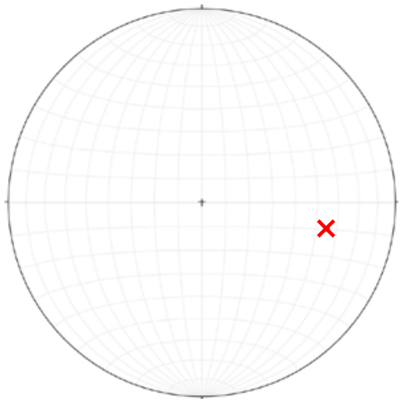
Counted in from the wrong side of the stereonet

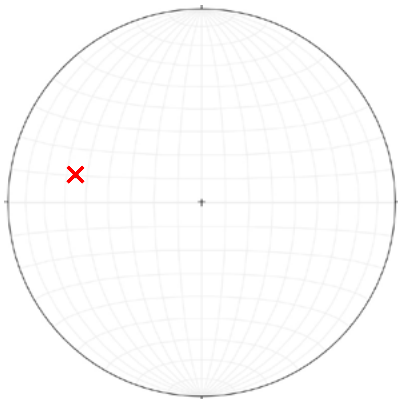
Measured from the centre of the stereonet not the outside

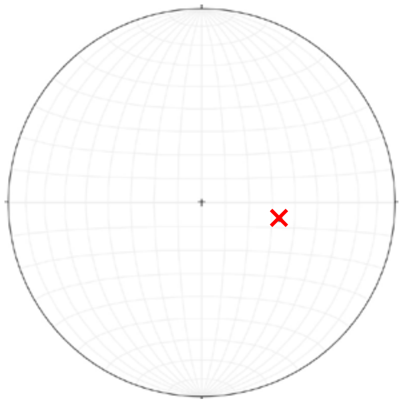
Just measured plunge not azimuth

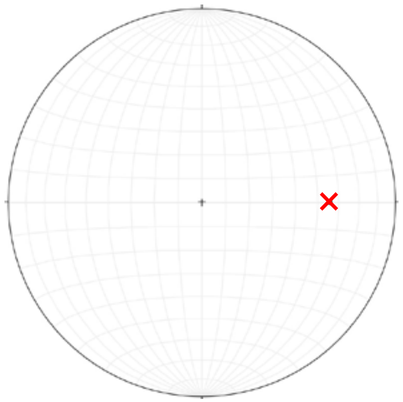
34/102

Correct







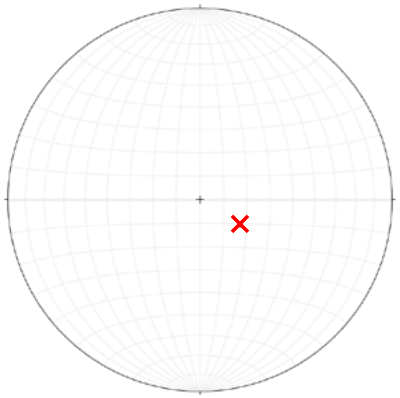


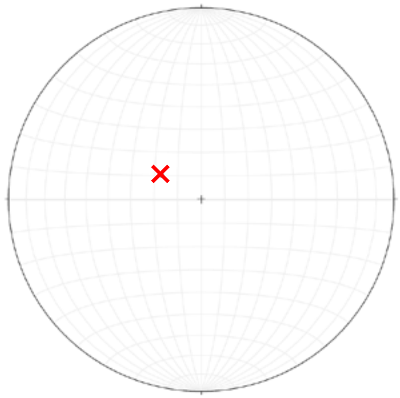
Exercise 3: Plotting planes as poles

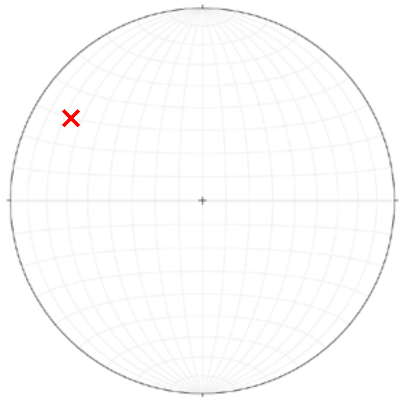
Back to questions

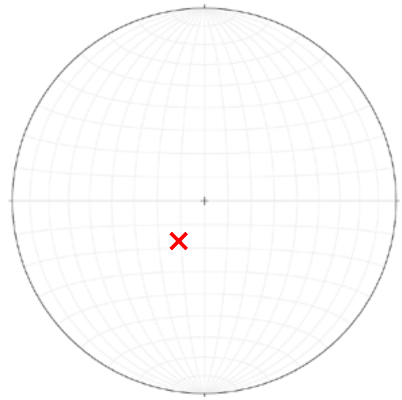
032/20NW

Correct









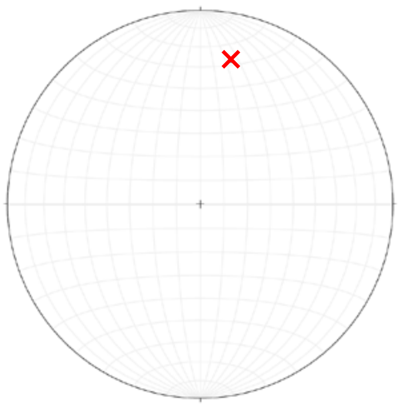
102/65S

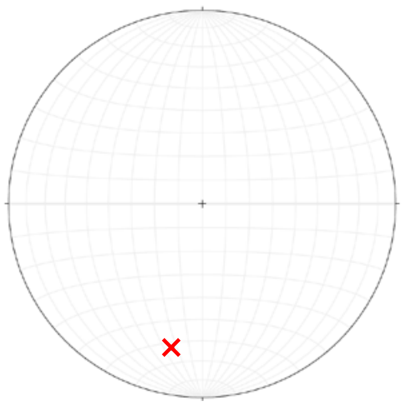
Correct

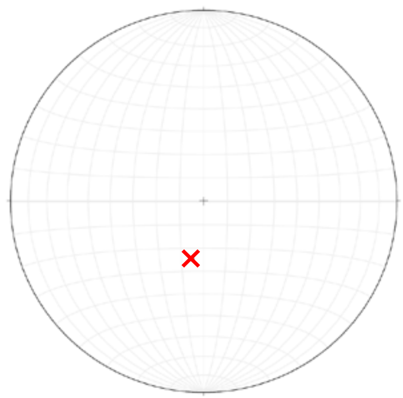
Counted in from the wrong side of the stereonet

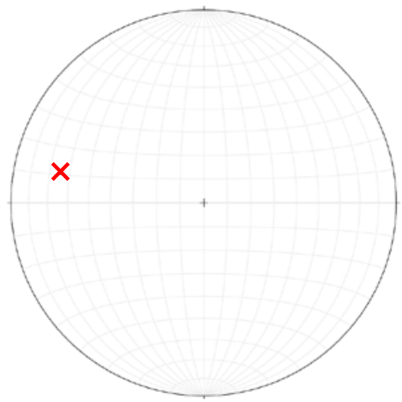
Have not added 90° when plotting

Rotated tracing paper to equator rather than to north pole







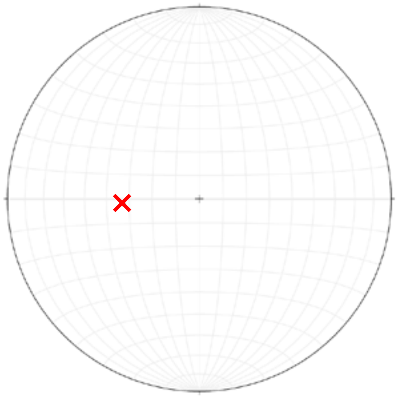


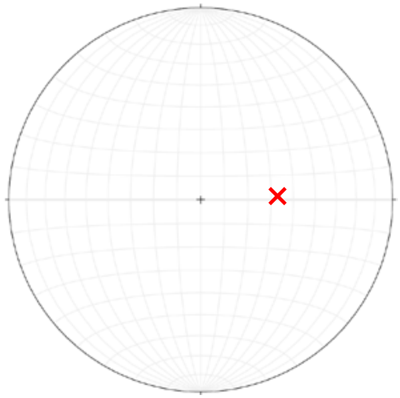
Exercise 3: Plotting planes as poles

Back to questions

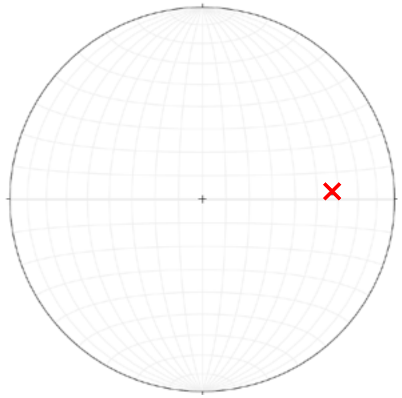
177/33E

Correct

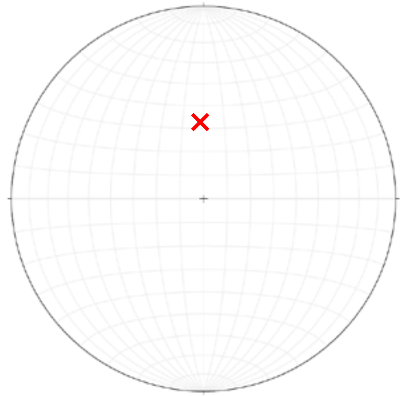




Counted in from the wrong side of the stereonet



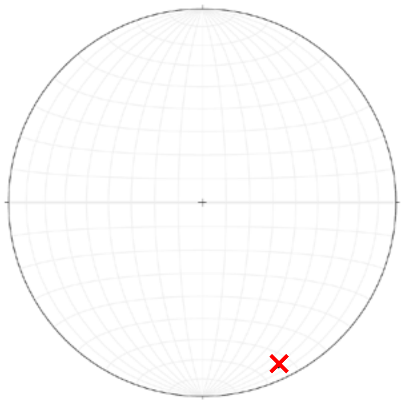
Have not added 90° when plotting

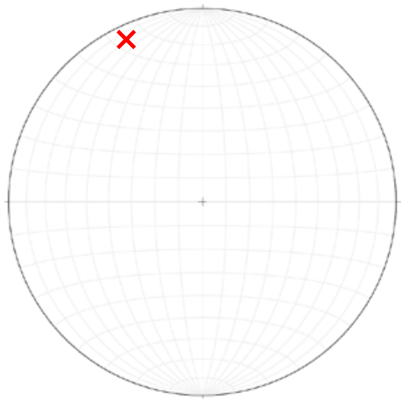


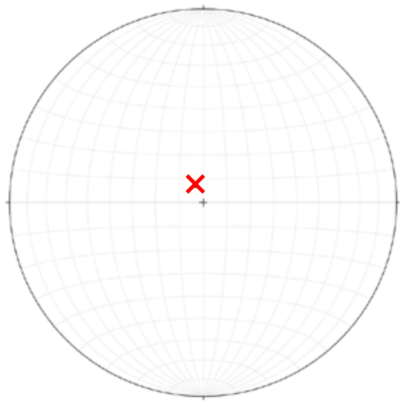
Rotated tracing paper to equator rather than to north pole

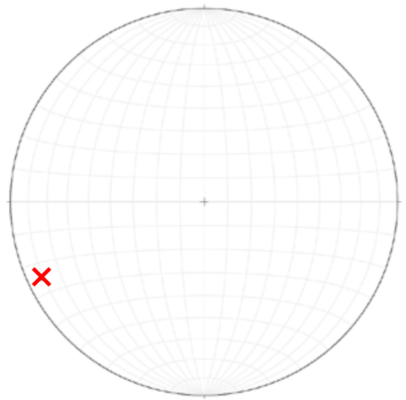
065/82NW

Correct









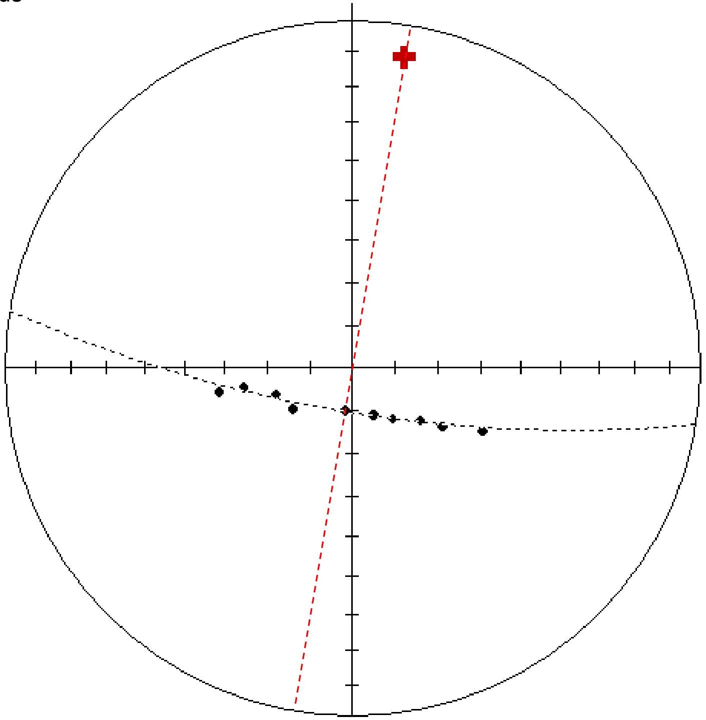
Practical answers

Question 1:

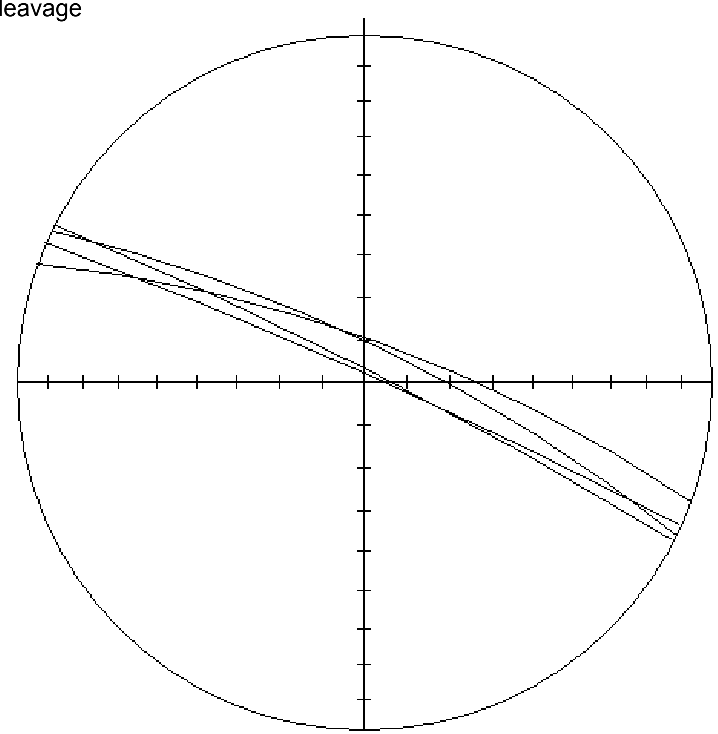
Back to questions

- Fold axis: ~10/010
- Fold axial plane: ~010/90
- Geometry of folds: Open/gentle
- Did the cleavage form at the same time as the folding? No it lies roughly perpendicular to the fold axial plane

Beds



Cleavage

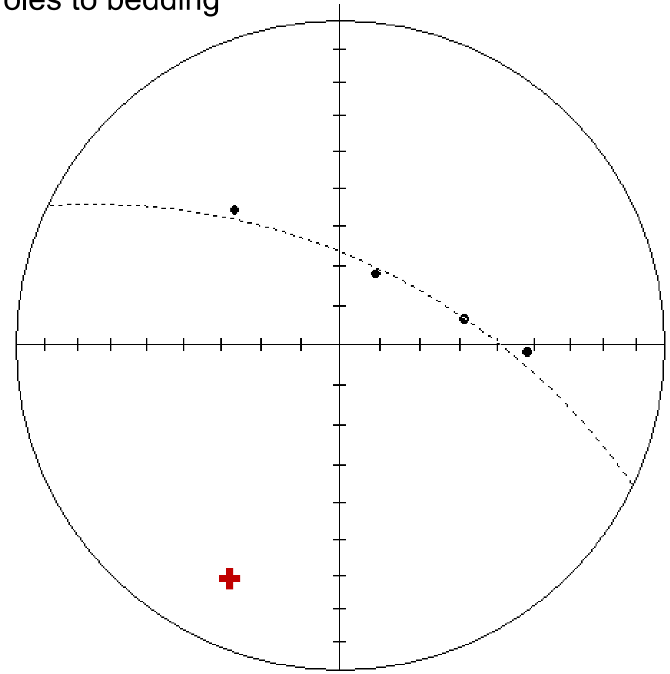


Question 2:

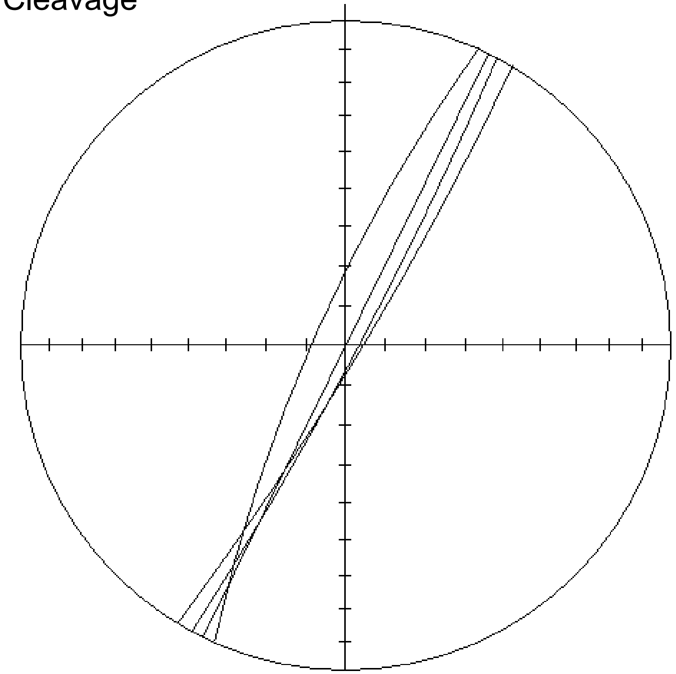
Back to questions

- Plunge/azimuth of the bedding/cleavage intersection lineation: ~20/208
- Fold axis: ~20/208
- How does this compare with the bedding/cleavage lineation? Same
- Where these minor folds formed in the same stress field as the cleavage? Yes
- Give your reason for this. Because their hinge lines plot close to the fold axis.

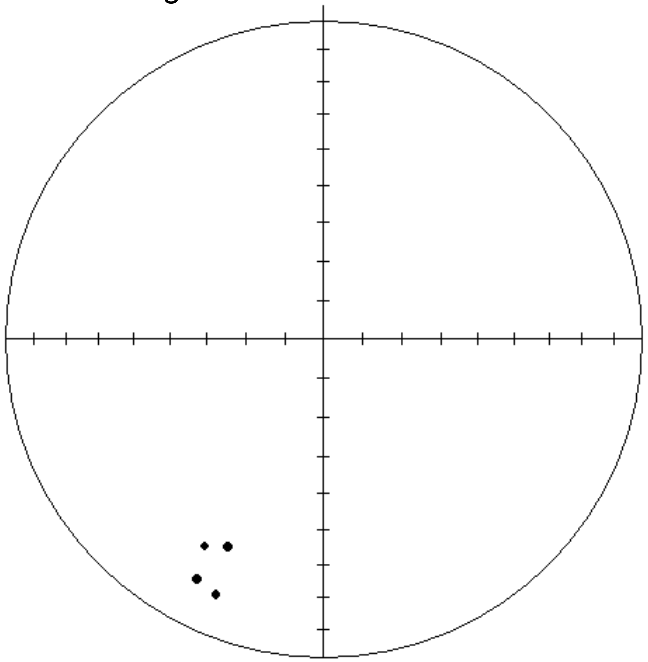
Poles to bedding



Cleavage



Minor fold hinges

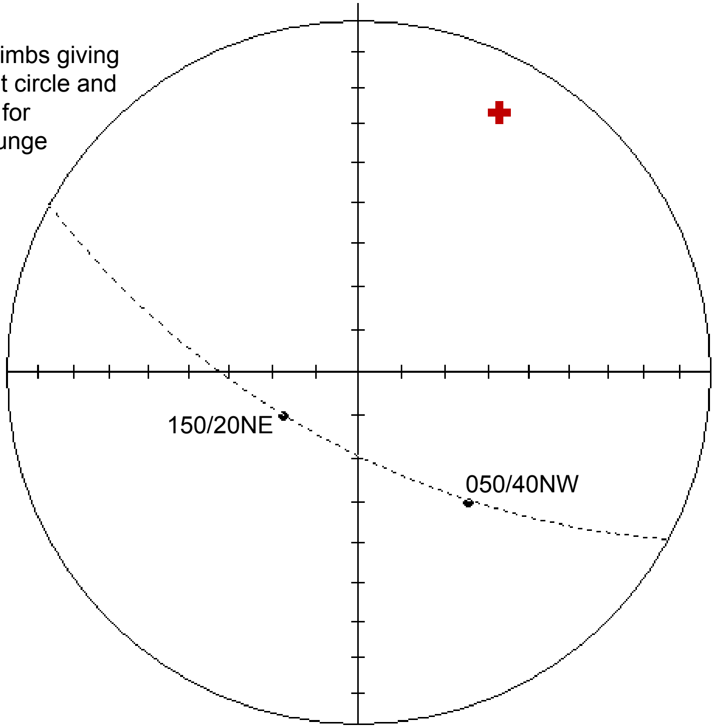


Question 3:

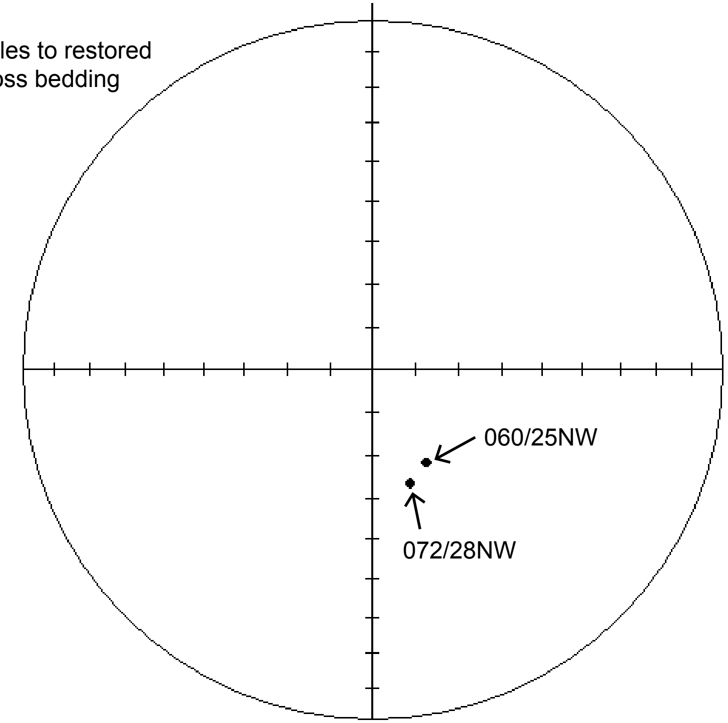
Back to questions

- Western limb: 072/28NW
- Eastern limb: 060/25NW
- Do these readings suggest a broadly similar migration direction? Yes

Plot of the two limbs giving the best fit great circle and so the fold axis for restoring the plunge of the fold



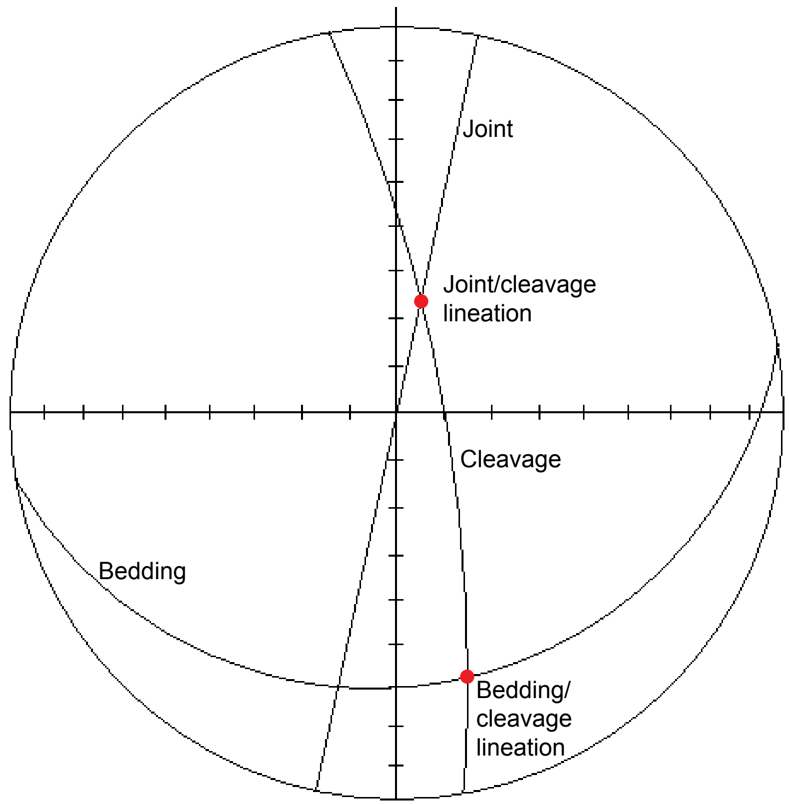
Poles to restored cross bedding



Question 4:

Back to questions

- Cleavage: 170/80E
- The lineations give two points the cleavage must pass through. Lining these up on a great circle gives the great circle of the cleavage.



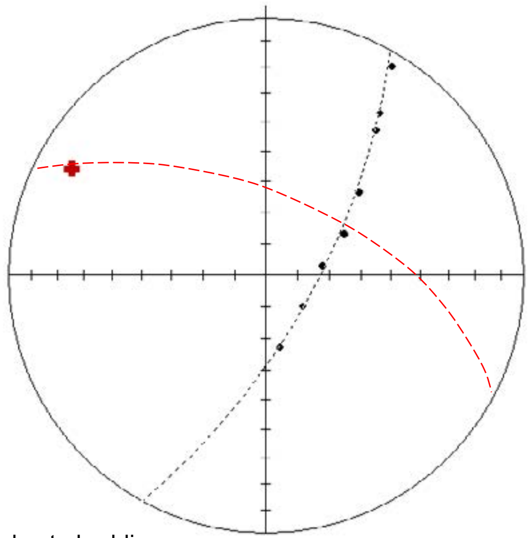
Back to questions

Question 5:

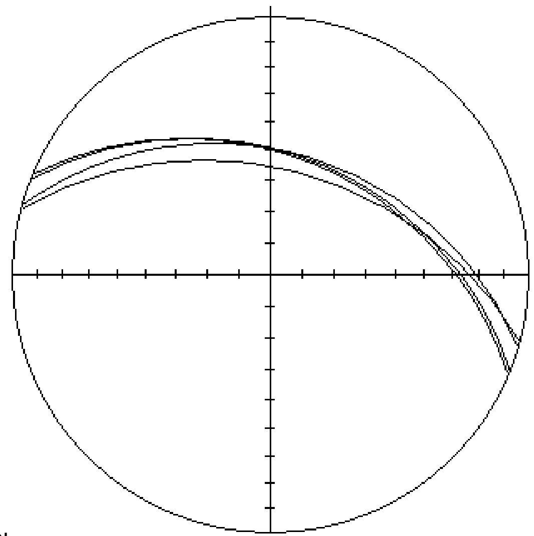
- Fold axis: ~15/299
- Fold axial plane: ~112/62NE
- Geometry of folds: Asymmetric, inclined
- How does the cleavage relate to the fold? Formed at same time as cleavage great circles lie close to parallel with the fold axial plane / cleavage poles lie on best fit girdle
- What type of faults are they and what sense of movement do the slickensides indicate? Dip slip normal faults
- Give the direction of sigma 3 during the formation of the faults: sigma 3 NNE-SSW
- In approximately which direction was the palaeocurrent flowing as given by the restored flute marks? SSW
- Give the direction of sigma 3 during the intrusion of the dykes: NNE-SSW
- Were the dykes, folds, faults and cleavage all formed under the same stress field? If not, which set of structures came first? Folds and cleavage formed during an early period of compression, the faults and dykes were formed later during a period of extension. They must have formed later or they would have been deformed during the compressive phase
- From all the information available write a detailed geological history:

Geological History

- Sediments were deposited under varying conditions of higher (sand) and lower (muds) energy.
- Palaeocurrent directions during deposition of the sandstone beds were approximately towards SSW.
- The sandstones and shales were folded (asymmetric, inclined) and cleavage developed in a compressional stress regime with sigma 1 NNE – SSW and sigma 3 vertical.
- In a new extensional stress regime – sigma 3 NE – SW, sigma 1 vertical, conjugate normal faults developed and igneous dykes were intruded.
- The rocks have also been metamorphosed, although from the information given, it is not possible to say when.

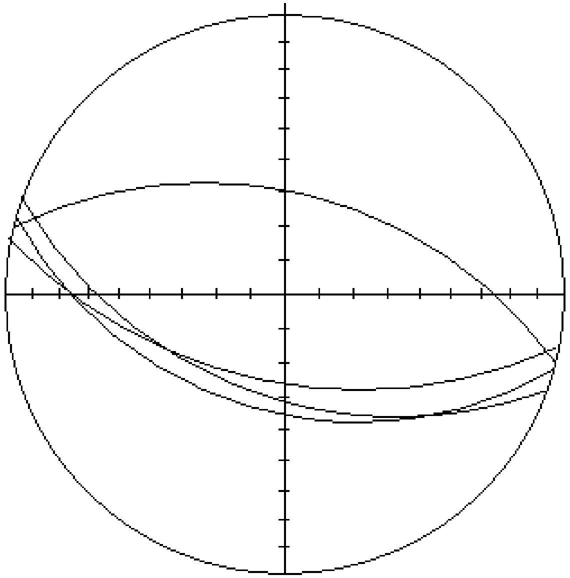


Poles to bedding

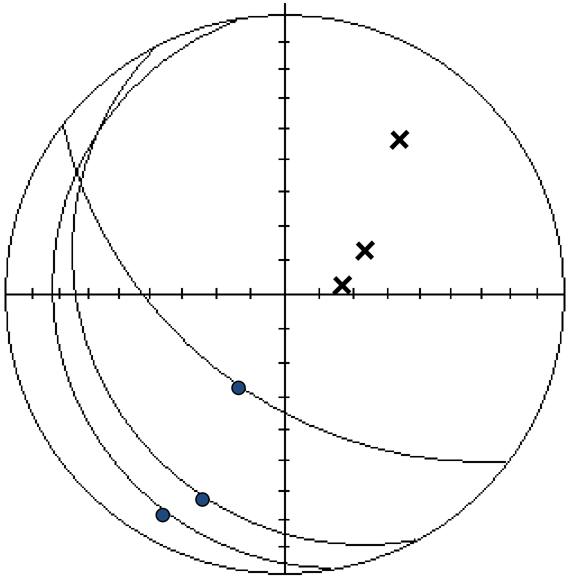


Cleavage

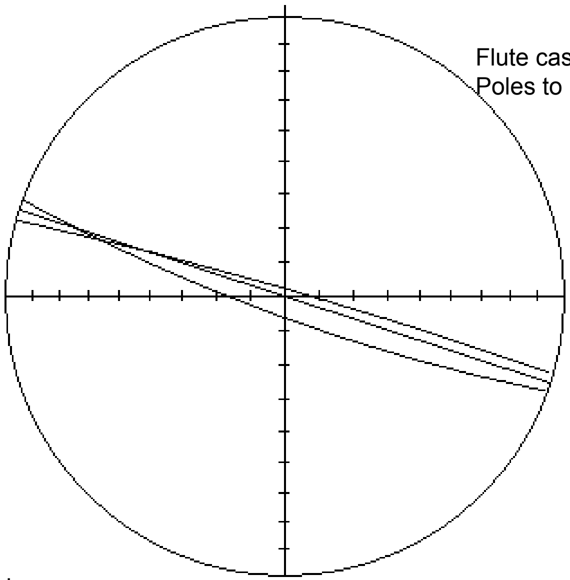
Back to questions



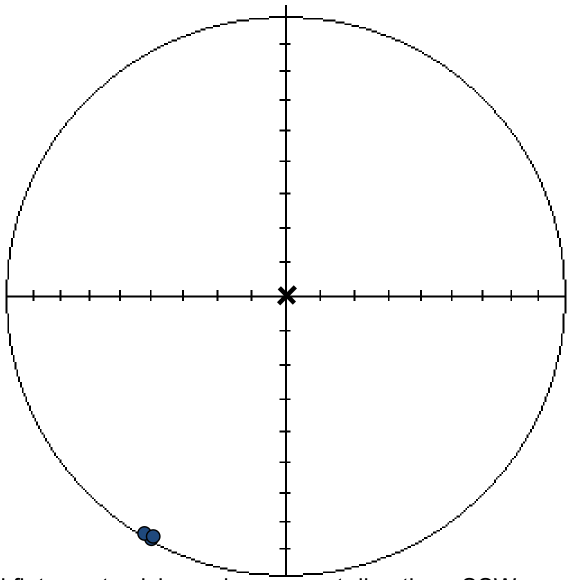
Normal faults with slickensides



Flute casts (circles)
Poles to bedding (crosses)



Dykes



Restored flute casts giving palaeocurrent direction ~SSW

Acknowledgements and references

Photographic sources:

Miller, M. 2012. Marli Bryant Miller Photography website [online]. [Accessed 12th September, 2012]. Available from www.marlimillerphoto.com/

Bibliography:

Leyshon, P. & R. Lyle (2004) Stereographic Projection Techniques in Structural Geology. Cambridge: Cambridge University Press.

This module is based on the stereonet component of the first year structural geology course of the Geological Sciences degree programme at the School of Earth and Environment, the University of Leeds.

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