Schmidt plot for structural analysis

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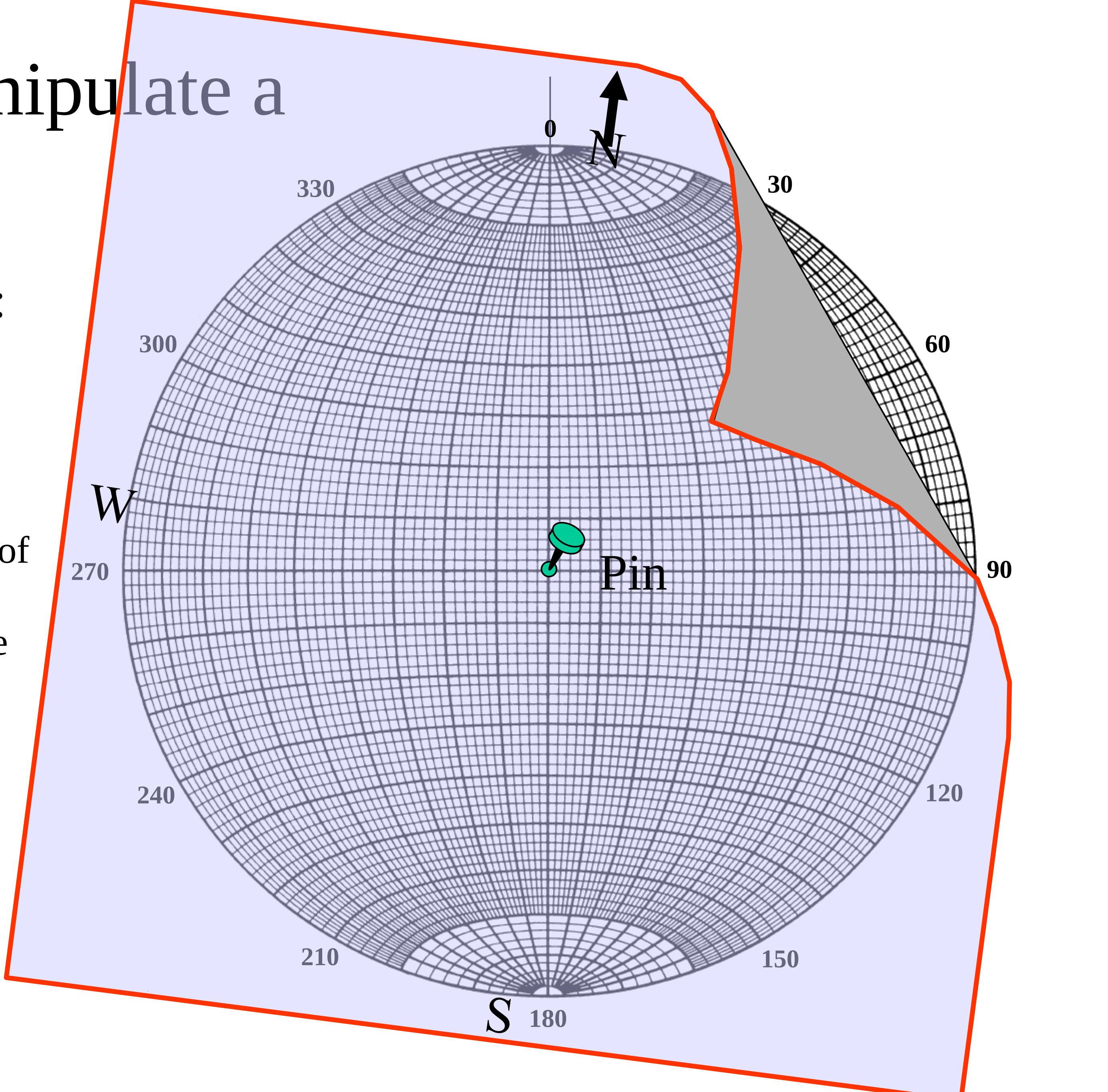
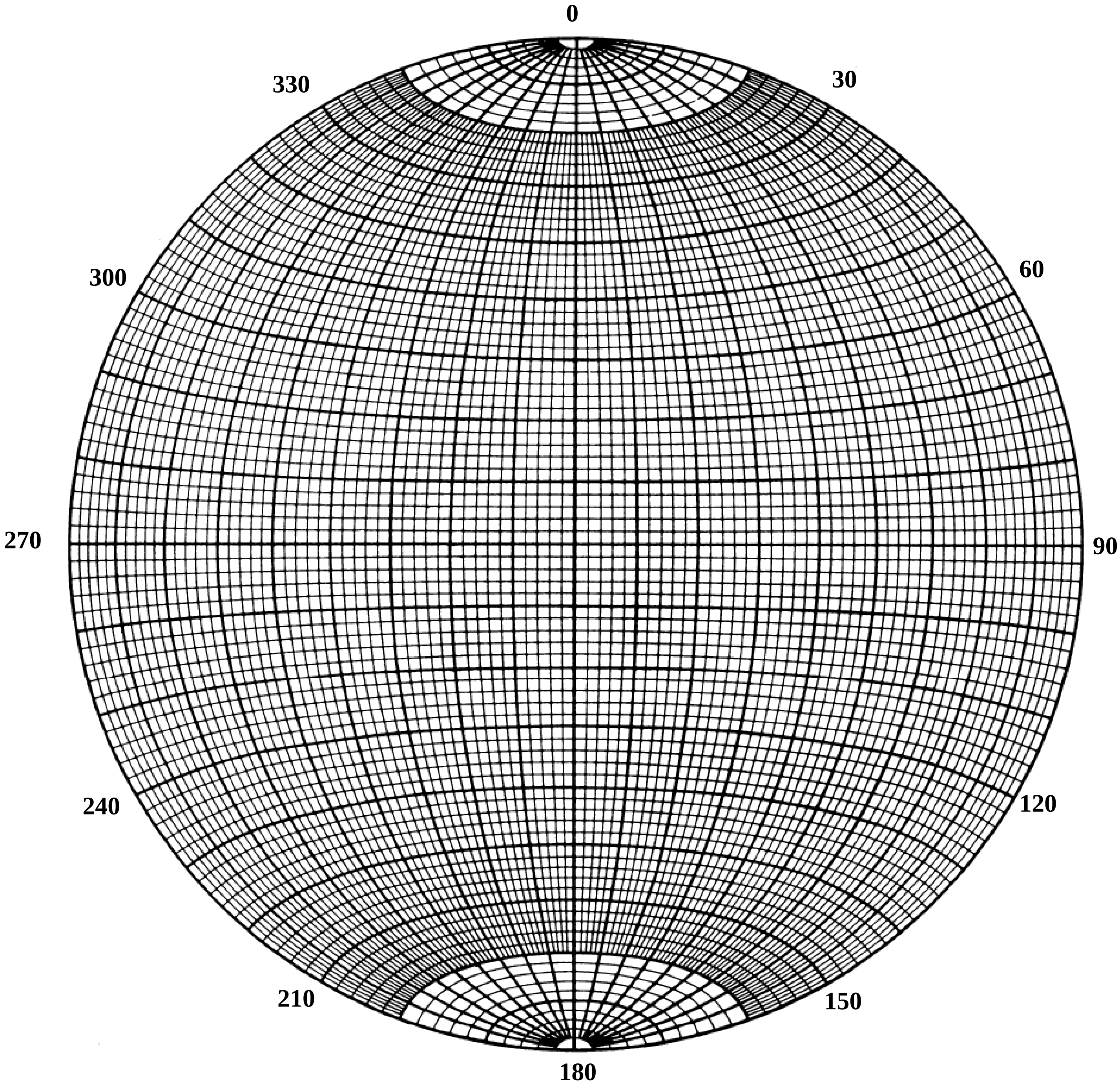
How to manipulate a Stereo Net

Material needed:

1. A stereonet that can be seen as a 3-D protractor
2. A transparent sheet of paper on which will be projected the true space oriented relative to North
3. A pin which allows rotation of the transparent sheet relative to the net




0
30
60
90
120
150
180
210
240
270
300
330

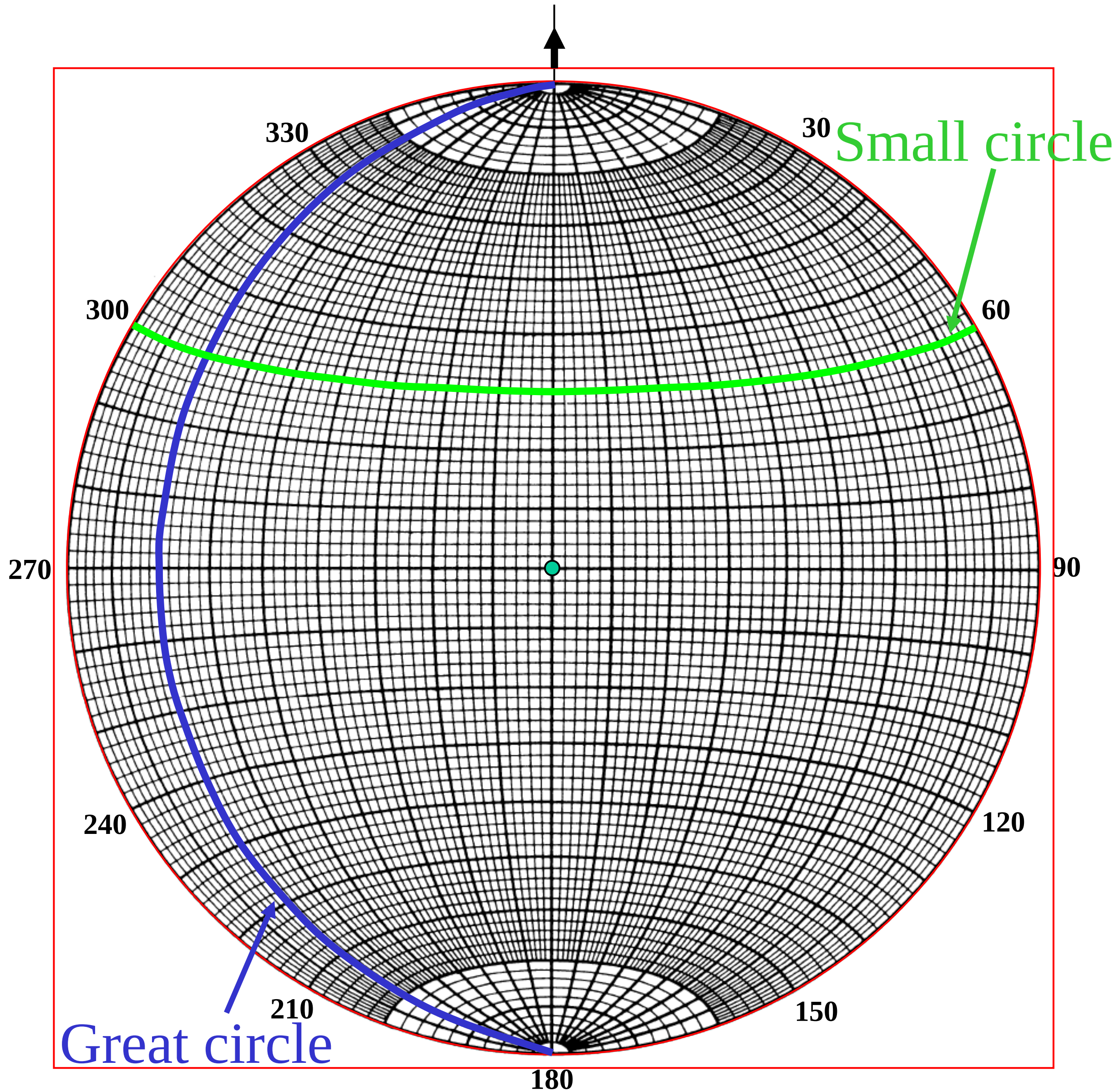
How to manipulate a stereonet

All the manipulations explained in this document are valid for both SCHMIDT and WULFF nets

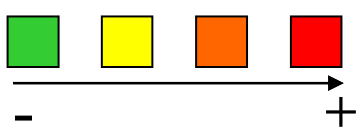
We use SCHMIDT

as it is the best stereonet for structural interpretation

(see the last slide for discussion)



Difficulty scale for the manipulations



The two principal types of object that can be represented on a Schmidt (or a Wulff) net are planes and lines.

Planes
- Bedding
- Axial plane
- Fracture
- Faults
- Etc..

Lines
- Fold axis;
- Lineation;
- Well trajectory;
- Slickenside;
- Etc….

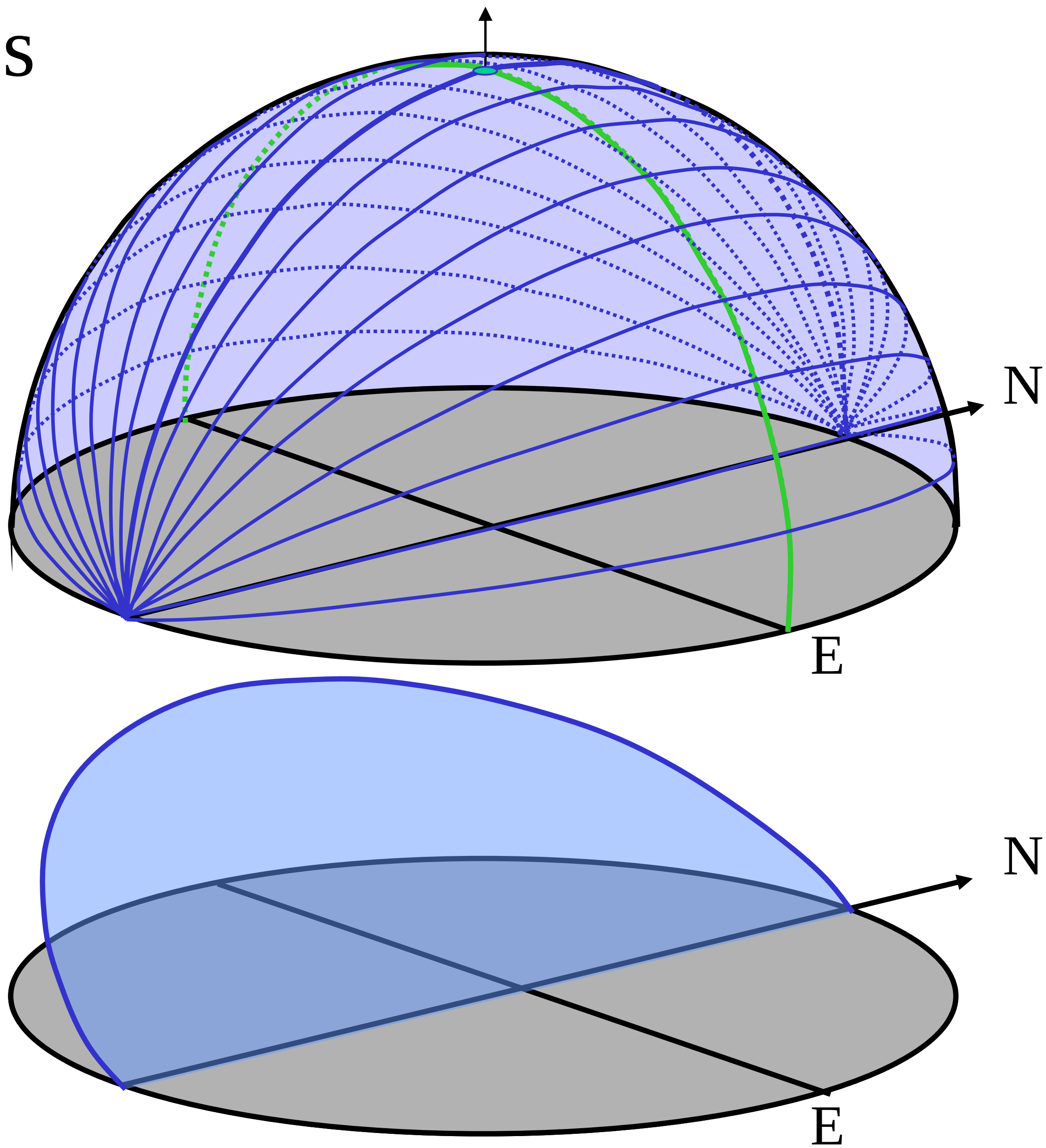
By definition, whatever the stereonet, both lines and planes are represented passing through the center of the sphere. So:

A line is represented by a point, its intersection with the sphere.

A plane is represented either by a Great Circle, the intersection of the plane with the sphere or by a point, which is the intersection of the plane’s normal (the line perpendicular to the plane) with the sphere of its pole .

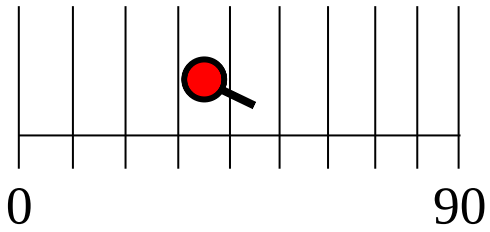
Great Circles

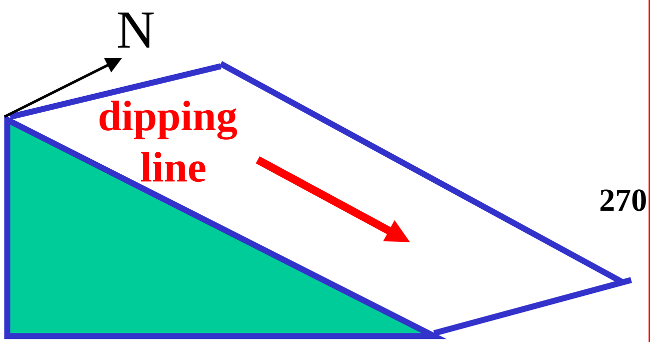
A great circle corresponds to a plane passing through the center of the hemisphere

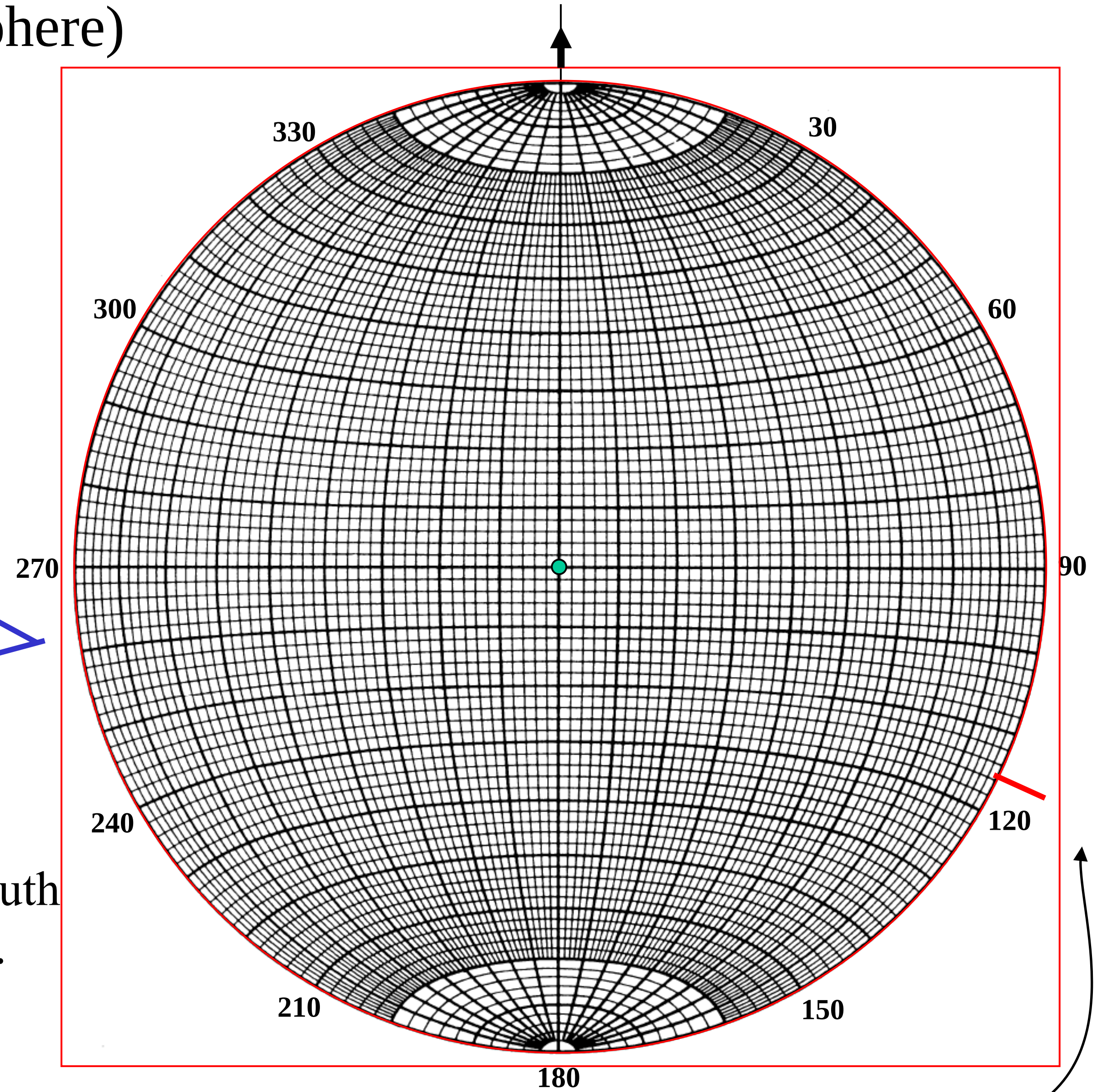


How to plot a plane on a Schmidt net U.H.? SLB Method - 1 (U.H.=Upper Hemisphere)

Ex: 35 dg to N-115?







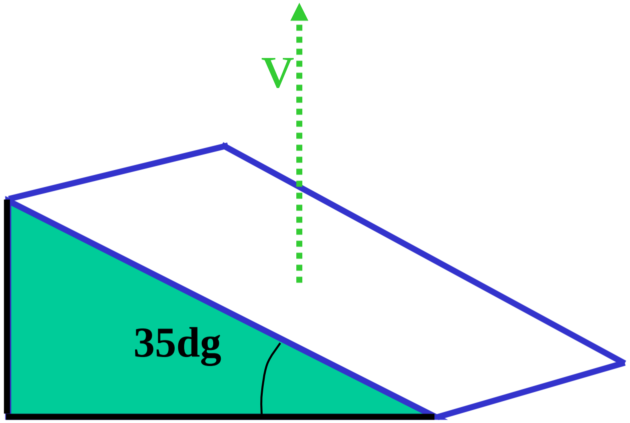
1- Mark the plane’s azimuth of 115 with a red tick.

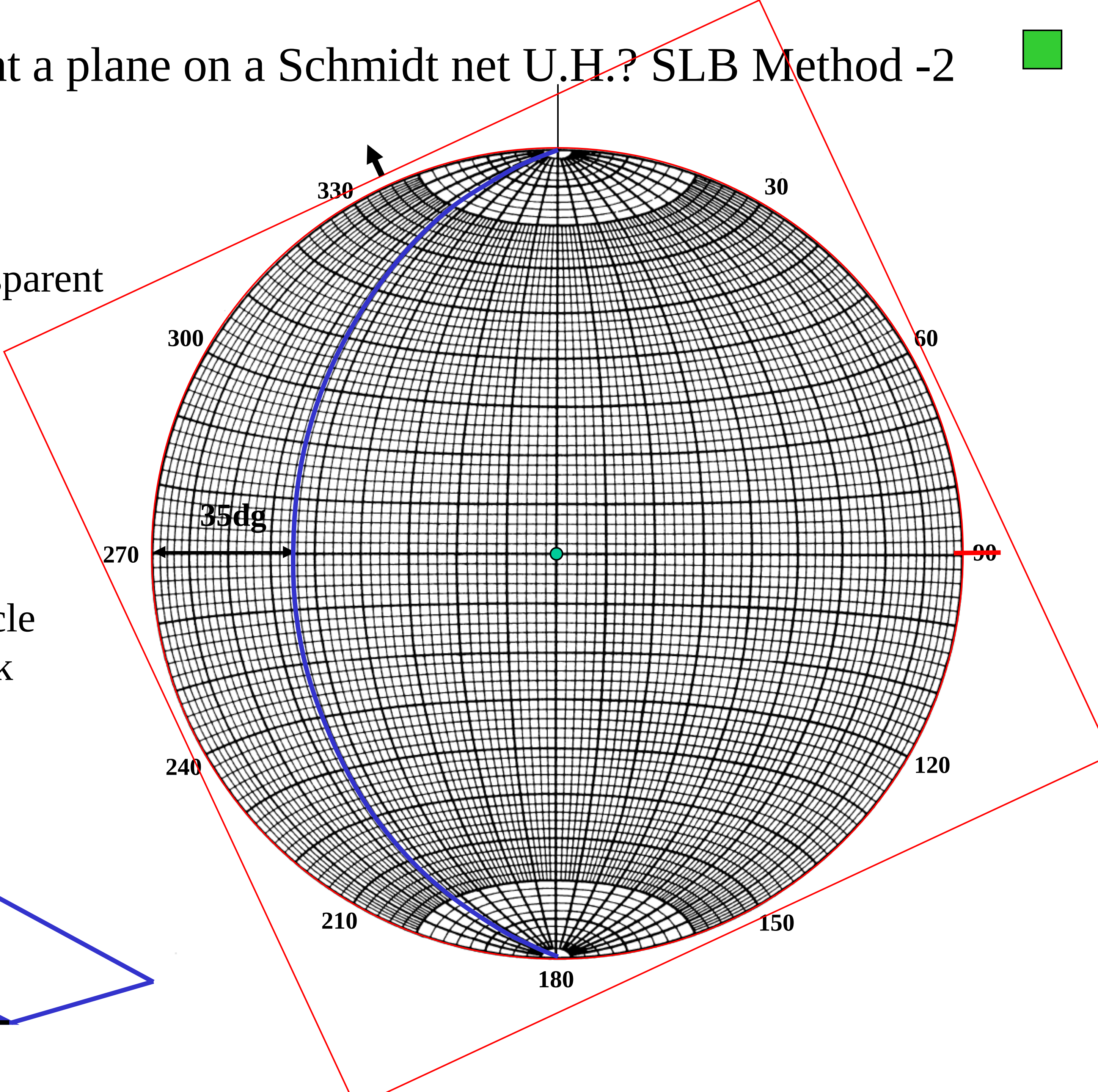
How to represent a plane on a Schmidt net U.H.? SLB Method -2

Ex: 35 dg to N115?

2- Rotate the transparent until this stick is Aligned E-W

3-Draw the Great Circle dipping 35 degree from the outer circle opposite to the tick

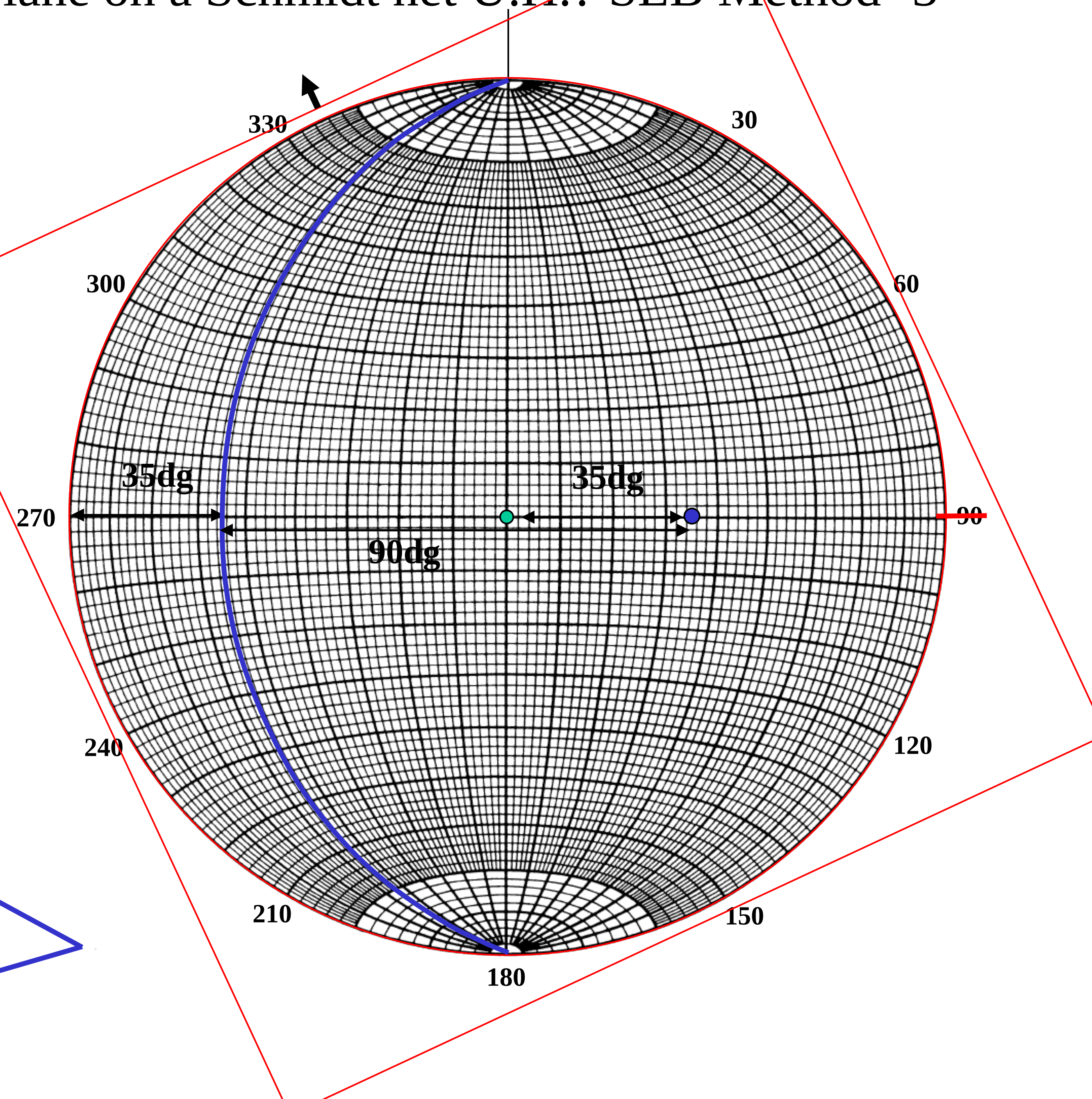


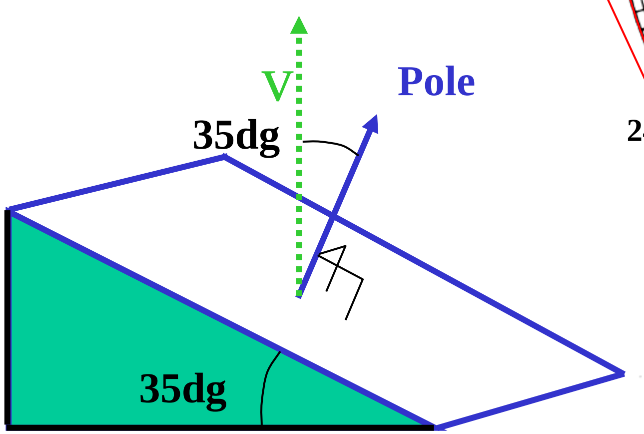


How to represent a plane on a Schmidt net U.H.? SLB Method -3

Ex: 35 dg to N115?

4- As GC is not easy to manipulate it is better to use its pole.
Plot the pole at 35 dg from center in the direction of the stick .
The pole is 90 degrees From the GC.

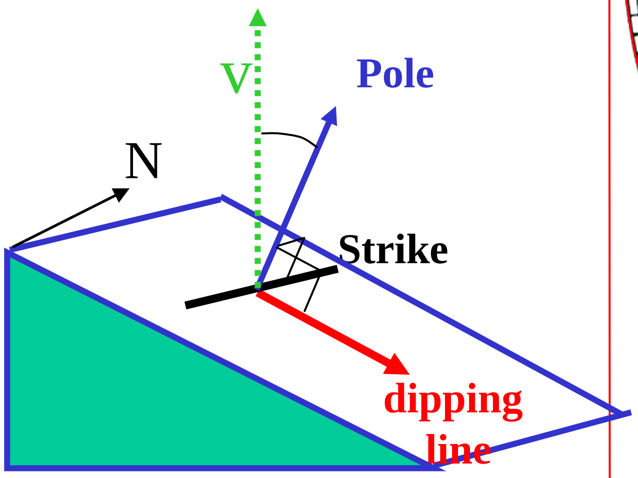


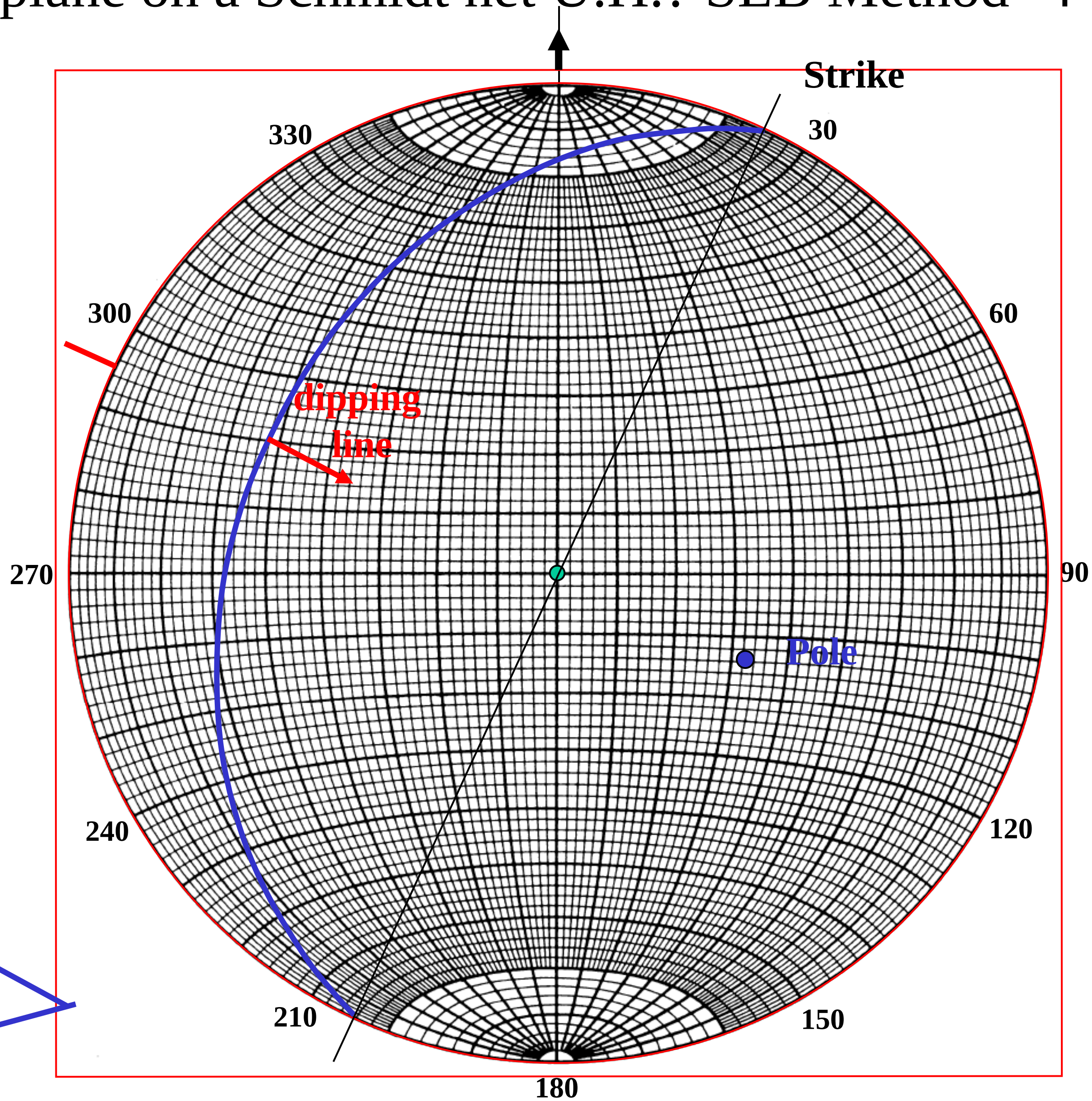


How to represent a plane on a Schmidt net U.H.? SLB Method -4

5- Rotate back to the initial position.

Note that in UH the pole has the same azimuth than the dipping line of the arrow plot.





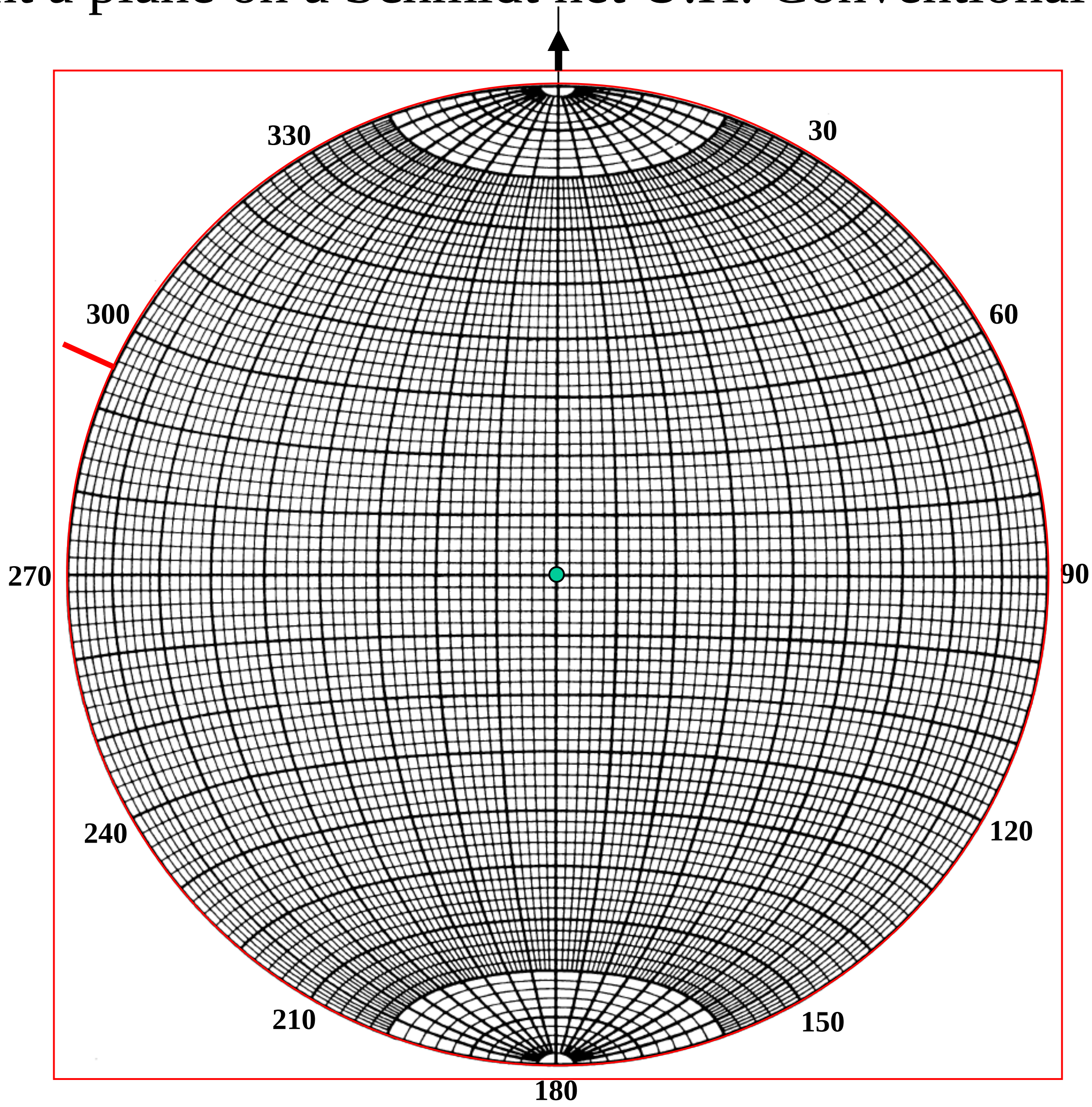
This is why SLB has chosen the UH ! but these lines are different.

How to represent a plane on a Schmidt net U.H. Conventional Method ? -1

Ex: 35 dg to N115

1-
Put a stick at the chosen azimuth +/- 180
(Because of UH)

115+180=295

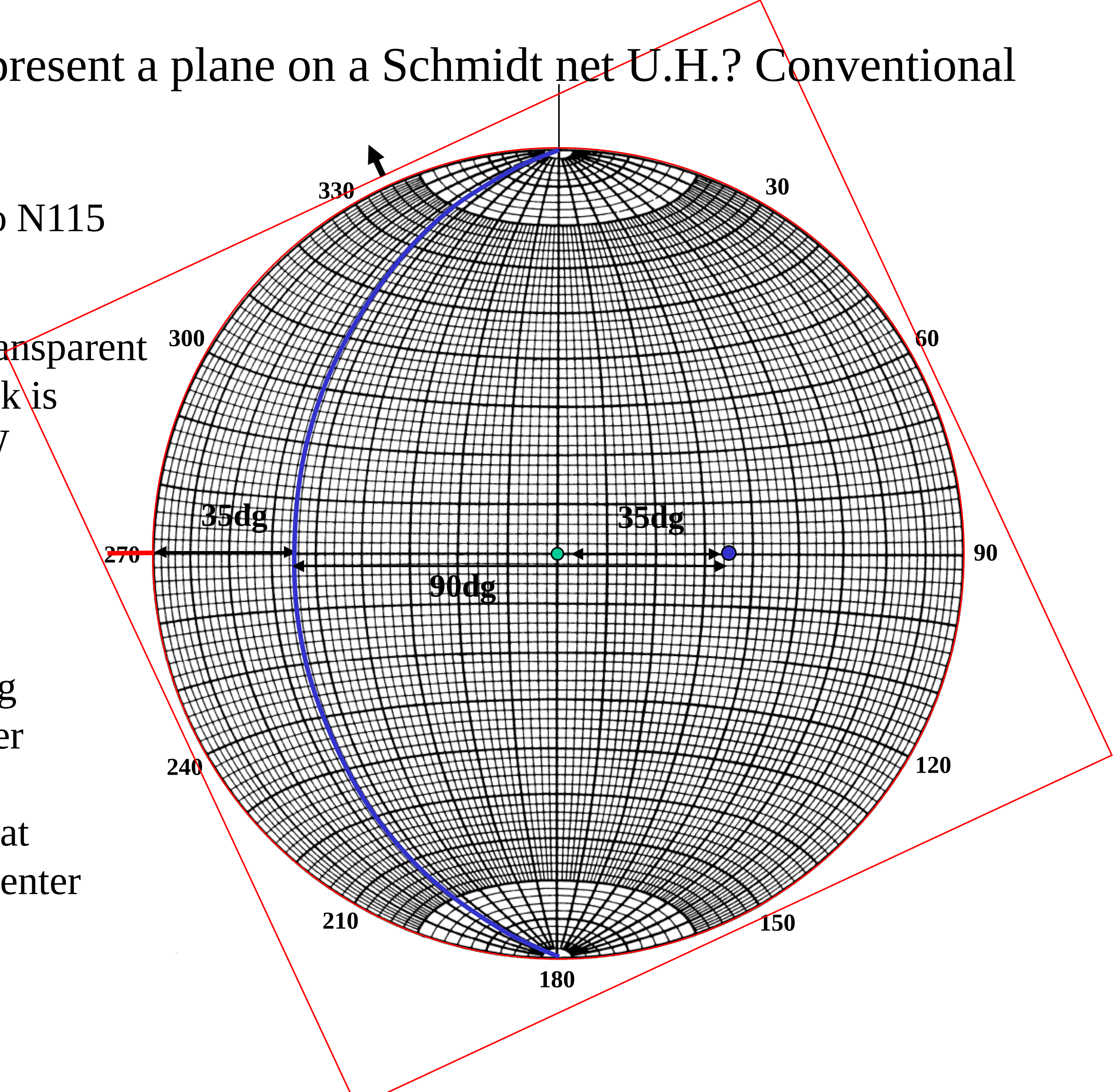


How to represent a plane on a Schmidt net U.H.? Conventional Method -2

Ex: 35 dg to N115

2-
Rotate the transparent until this stick is Aligned E-W

3-
Draw the Great Circle dipping 35 dg from the outer circle
And its pole at 35 dg from center



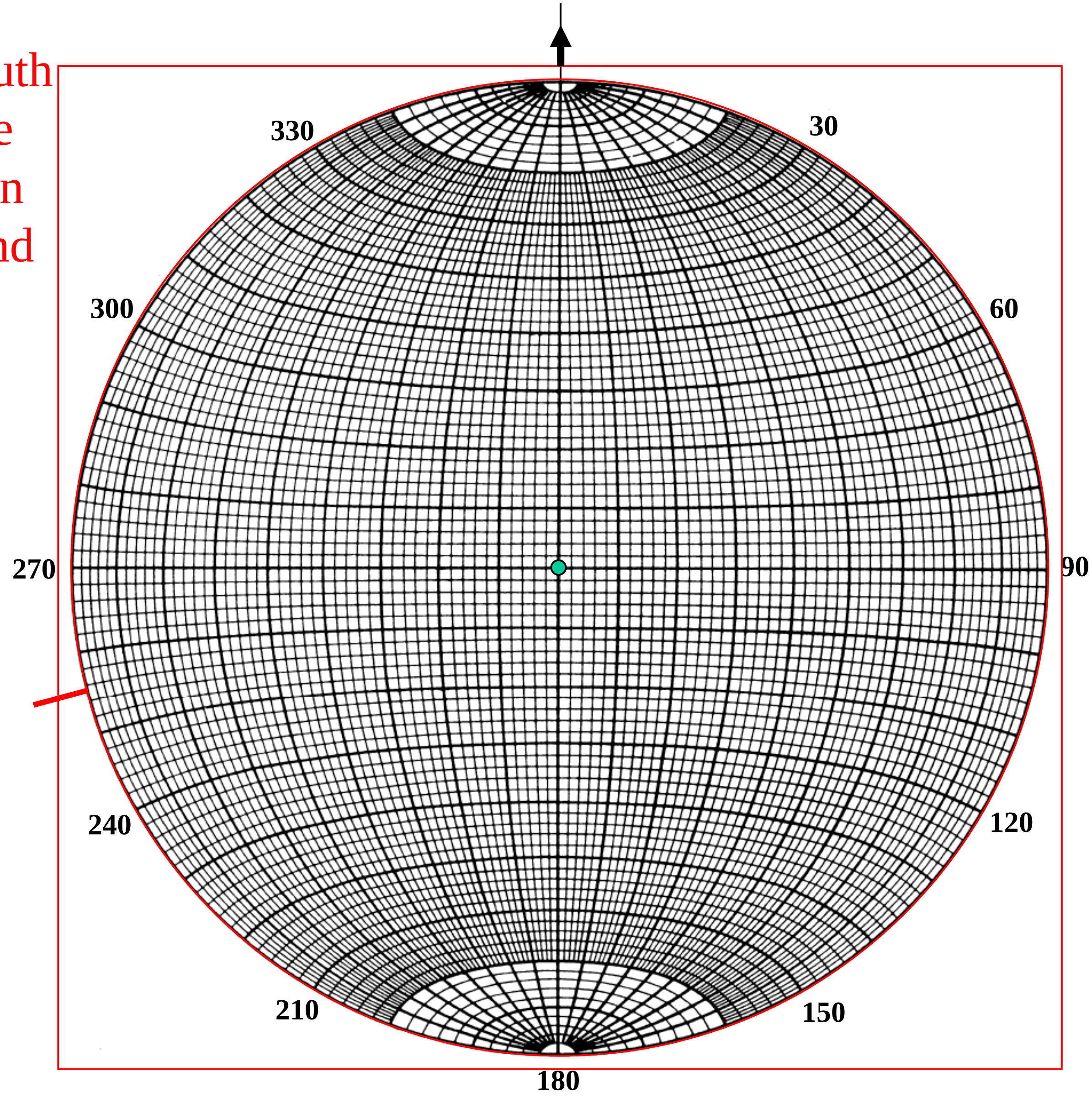
How to represent a line on a Schmidt net U.H.? -1

By convention the azimuth of a line is defined as the down-dipping orientation with respect to North, and its dip is measured with respect to the horizontal

Ex: 30 dg to N75?

1- Put a stick at the chosen azimuth +/- 180 (Because of UH)

75+180=255

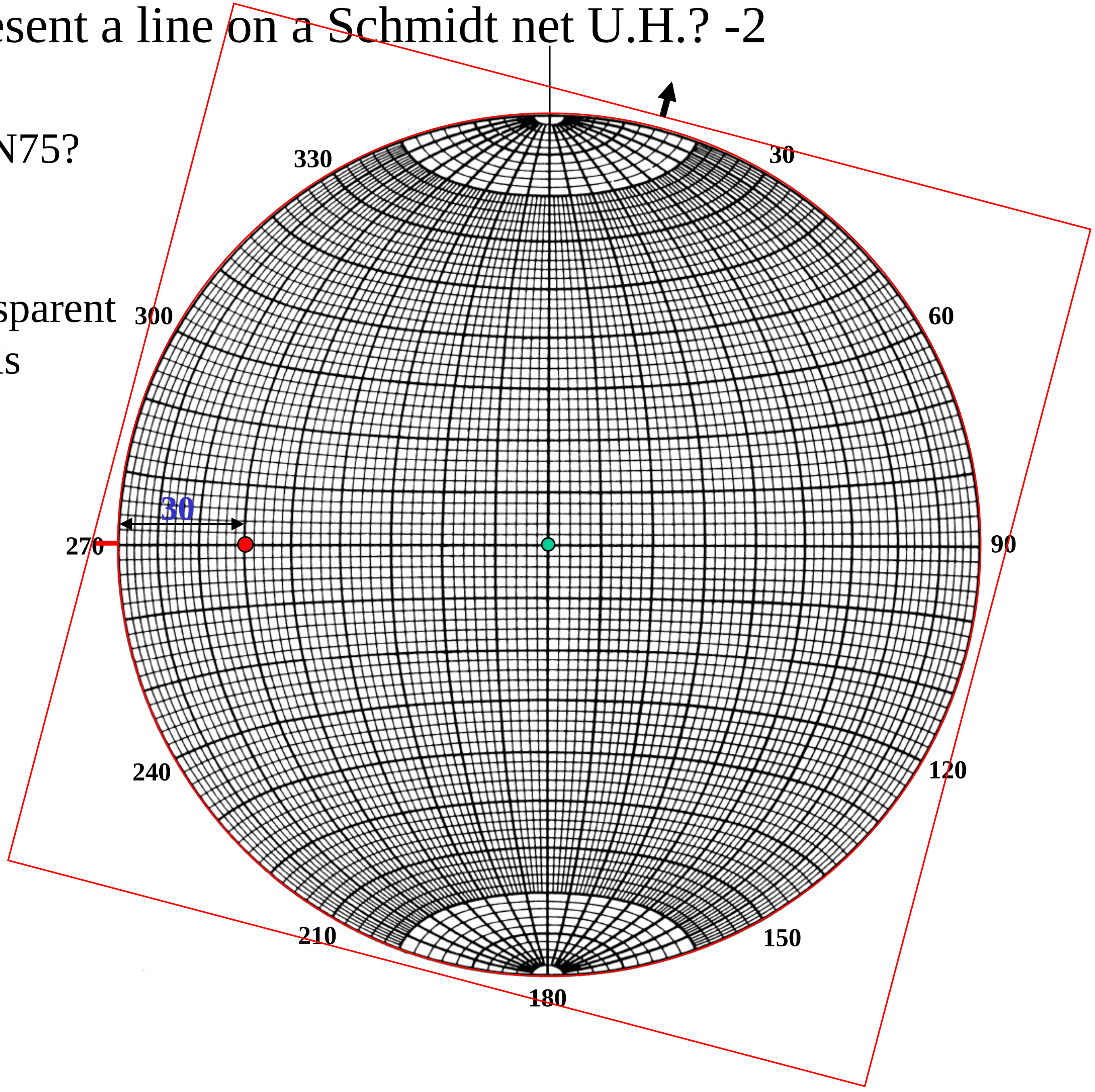


How to represent a line on a Schmidt net U.H.? -2

Ex: 30 dg to N75?

2-
Rotate the transparent until this stick is aligned E-W

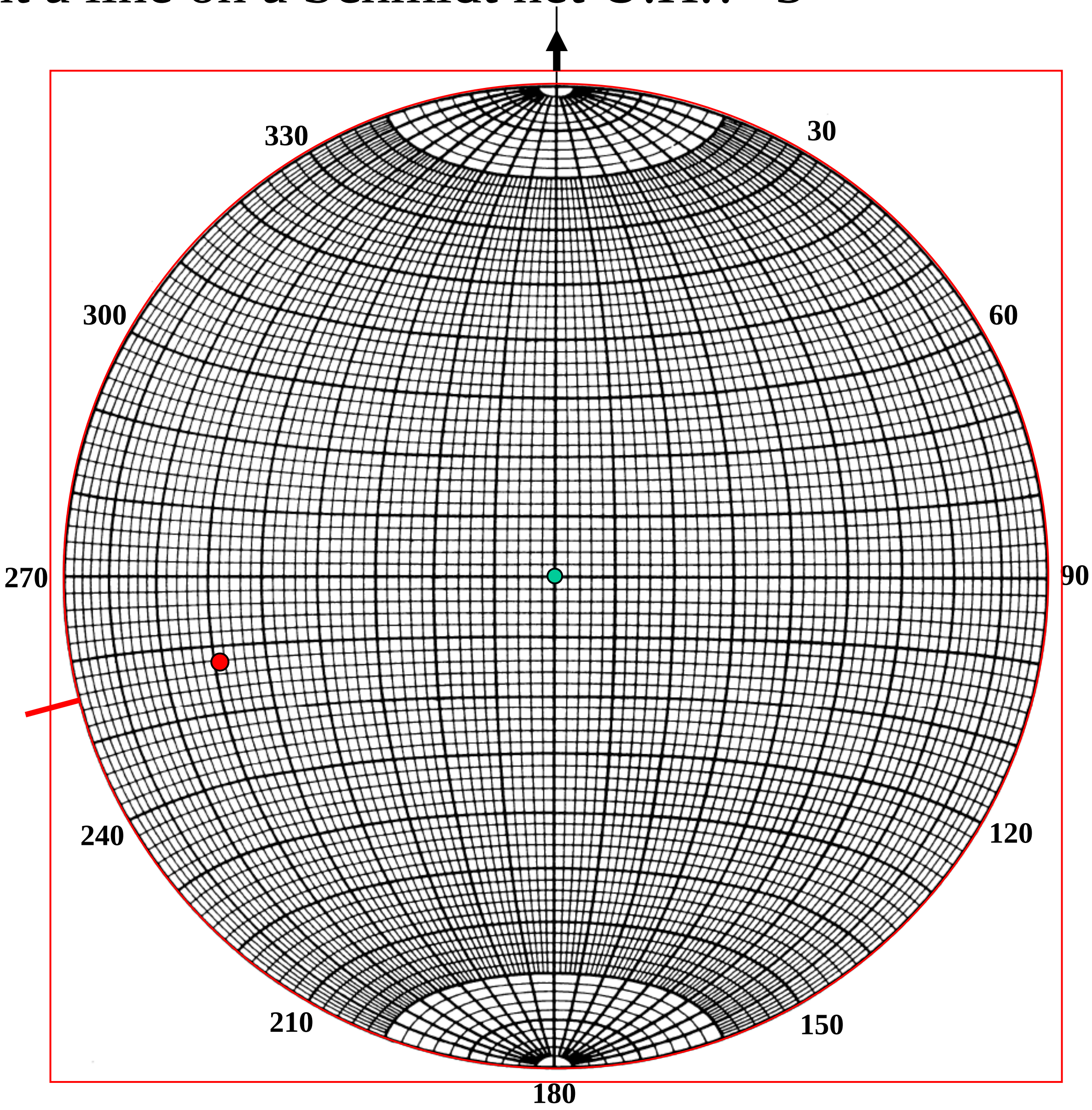
3-
Put a point at 30 deg of the outer circle



How to represent a line on a Schmidt net U.H.? -3

Ex: 30 dg to N75?

4-
Rotate back to the initial position

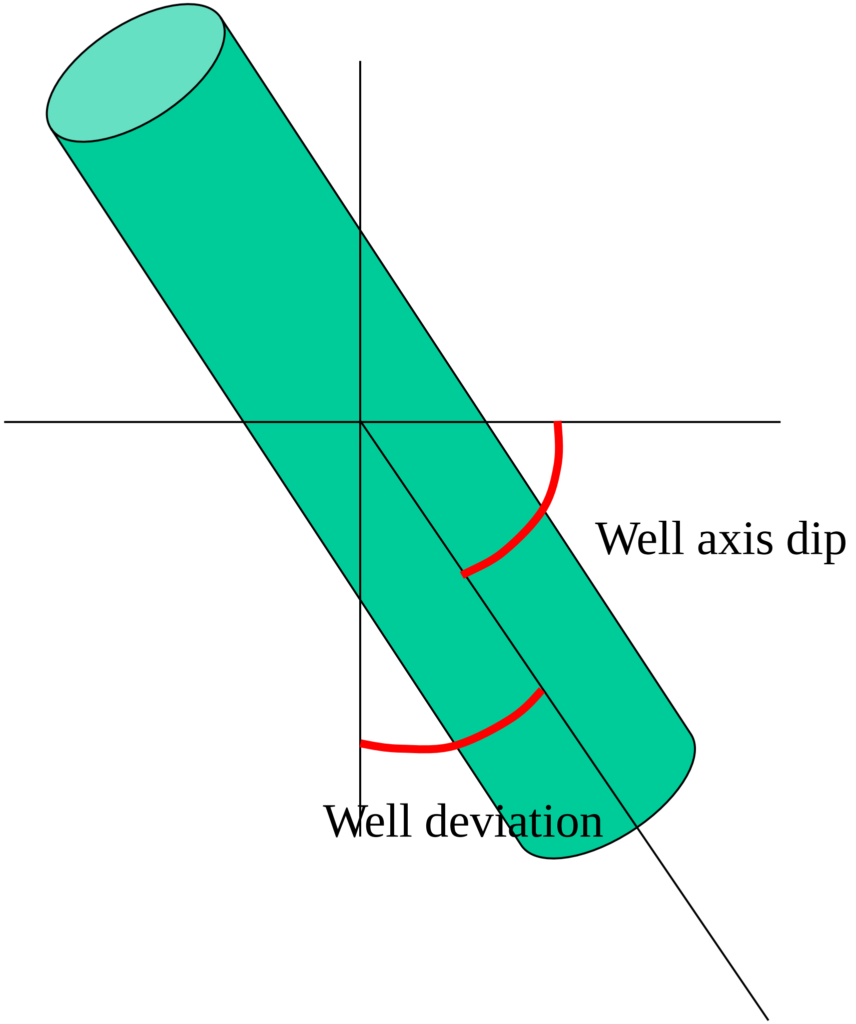


How to plot the axis of a deviated well ?

By convention:
The azimuth of a well is its down-hole orientation with respect to North as for any line.
But its deviation is an angle measured with respect to the vertical. This is opposite to the convention used for lines.

A well axis has to be plotted as a line whose azimuth is the well azimuth but whose dip is 90-well deviation

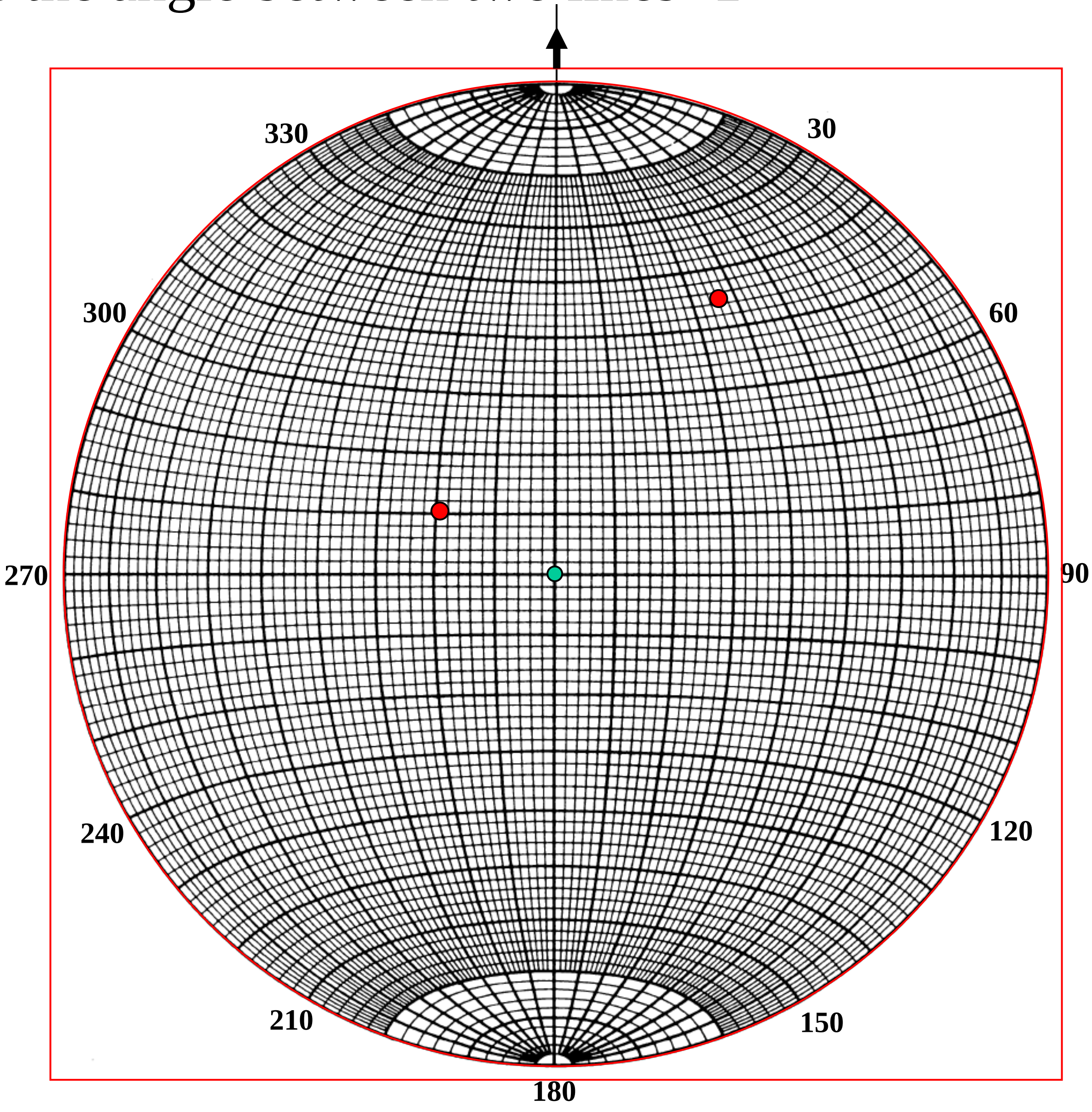
Example:
A well deviated by 40 deg to N-45 has to be plotted as a line dipping 50 (90-40) to N-45



How to measure the angle between two lines -1

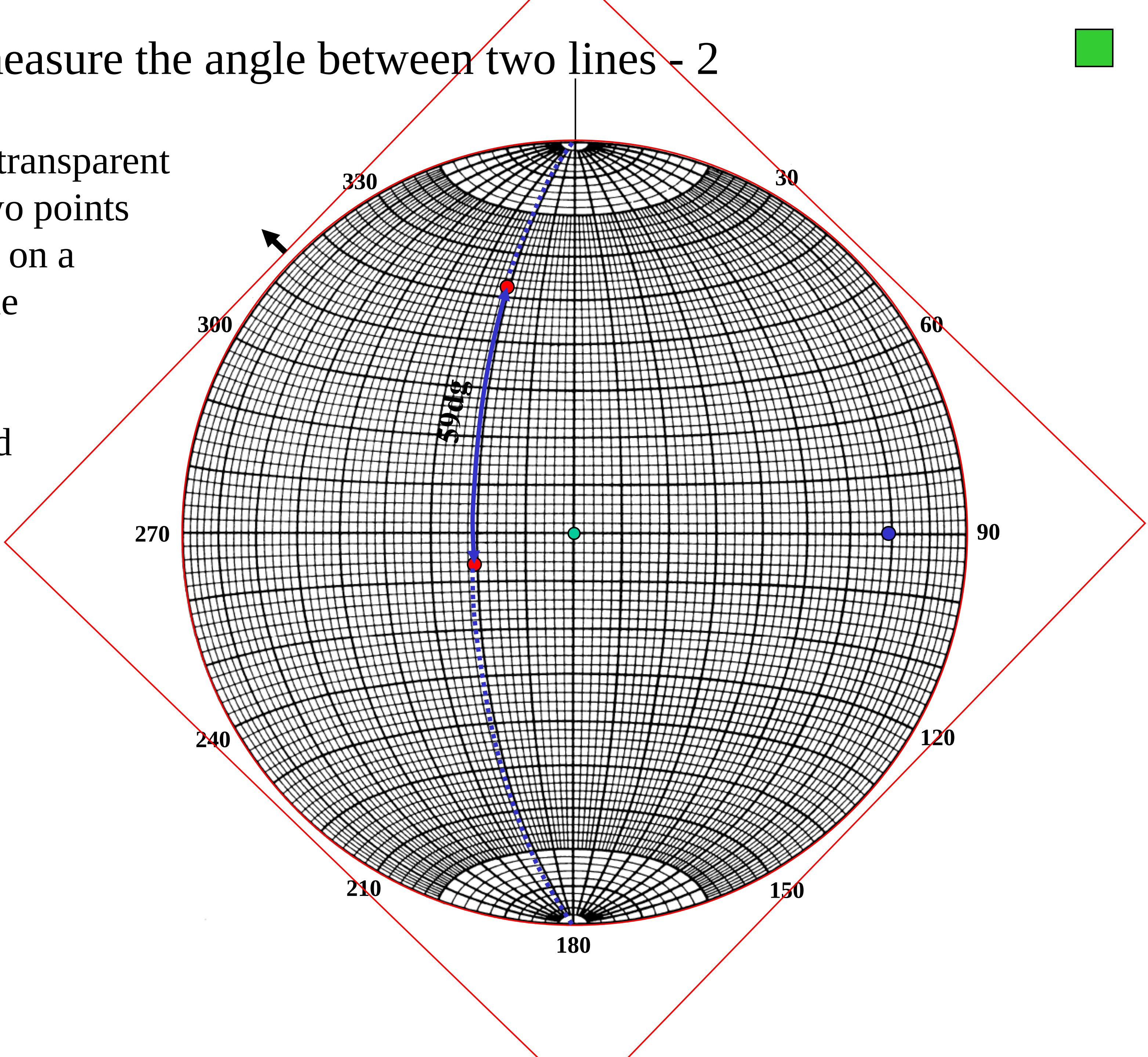
1-
plot the
two lines
on the net

68 to 120 (+180)
35 to 210 (-180)



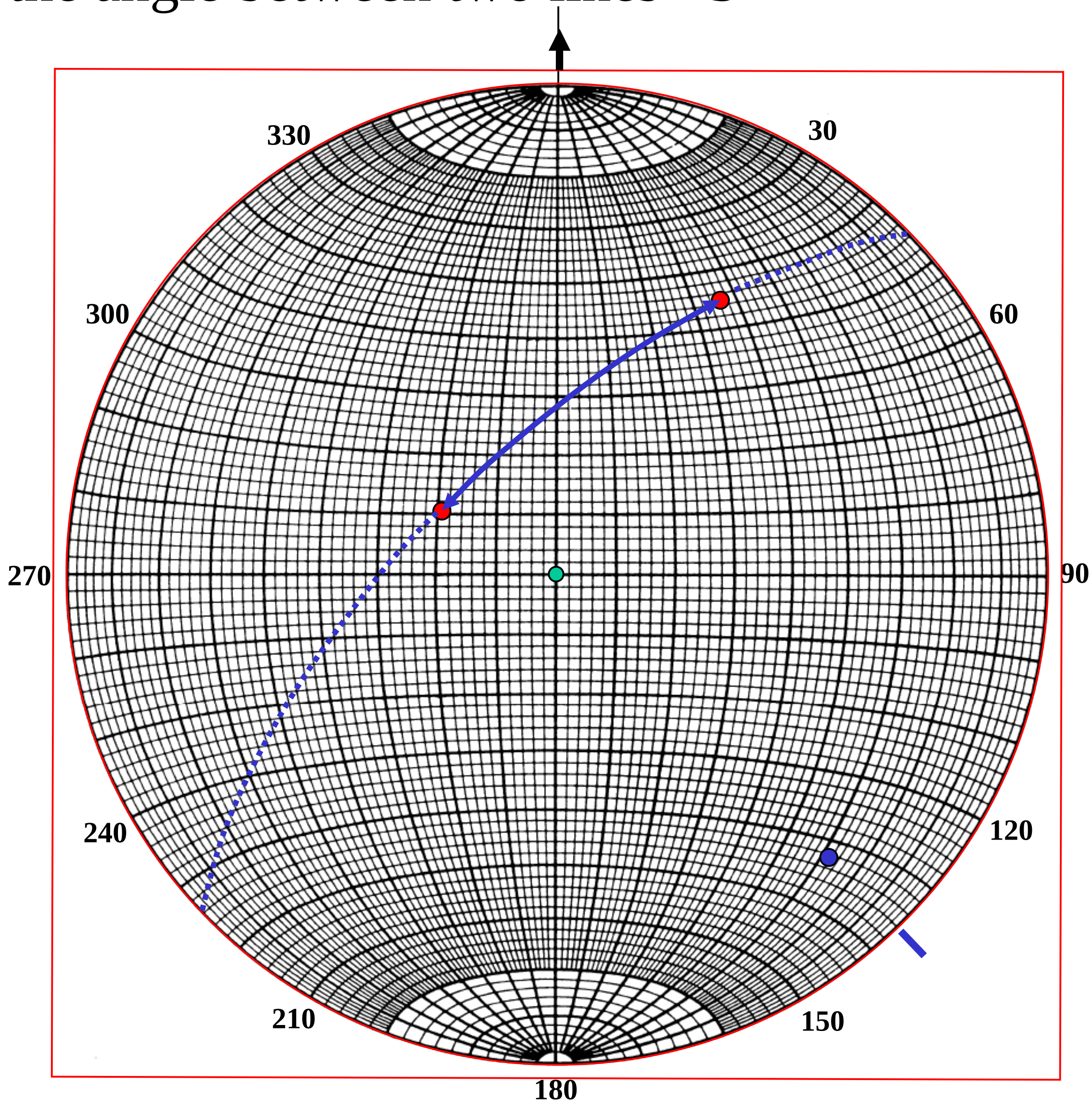
How to measure the angle between two lines - 2

Rotate the transparent until the two points are aligned on a Great Circle on which the angle is measured (59 dg).



How to measure the angle between two lines - 3

The blue great circle corresponds to the plane that contains the two lines.
It is
69 to N-136



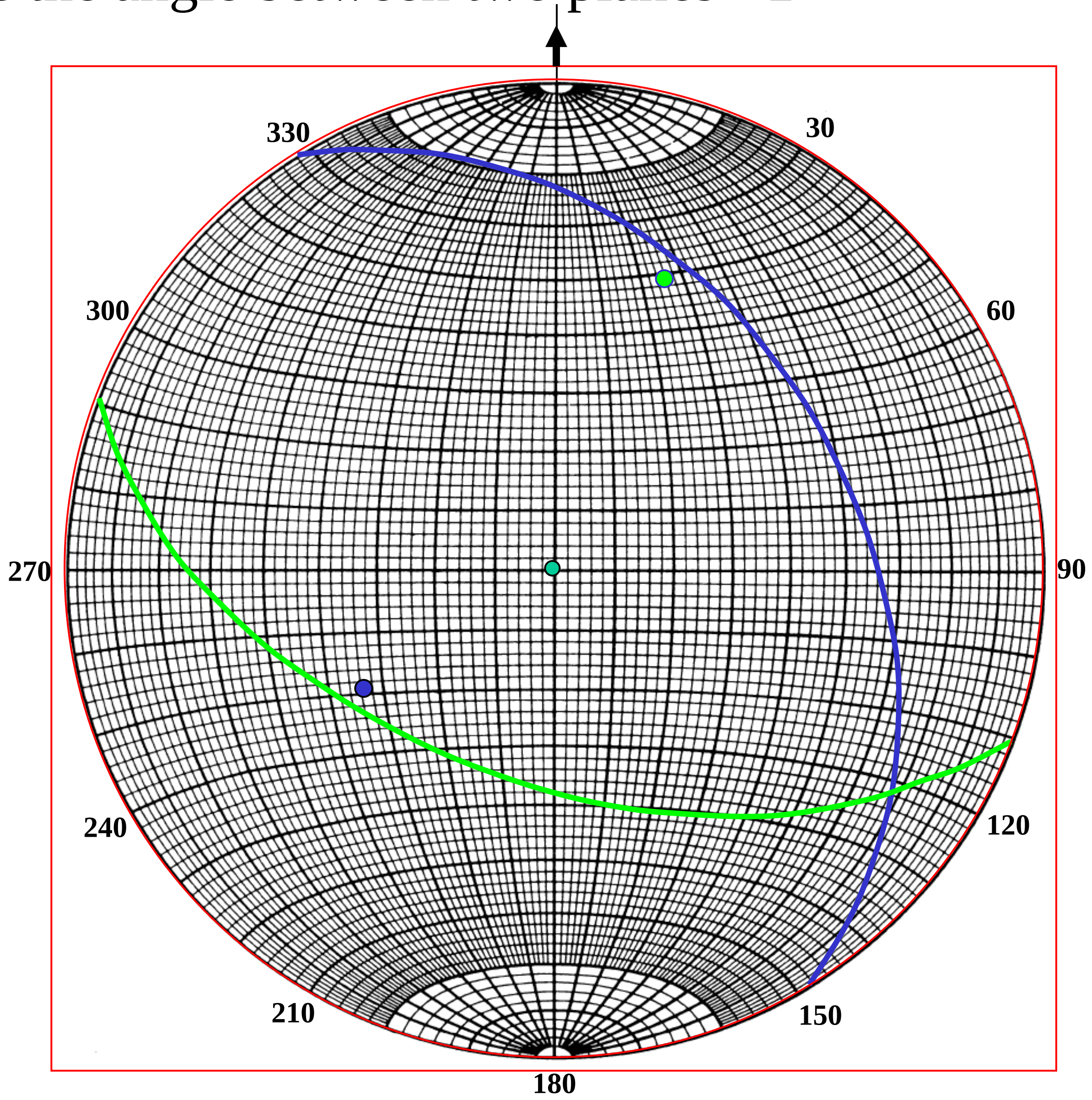
How to measure the angle between two planes - 1

ex:

Strati: 38 to N-238

Fract: 54 to N-20

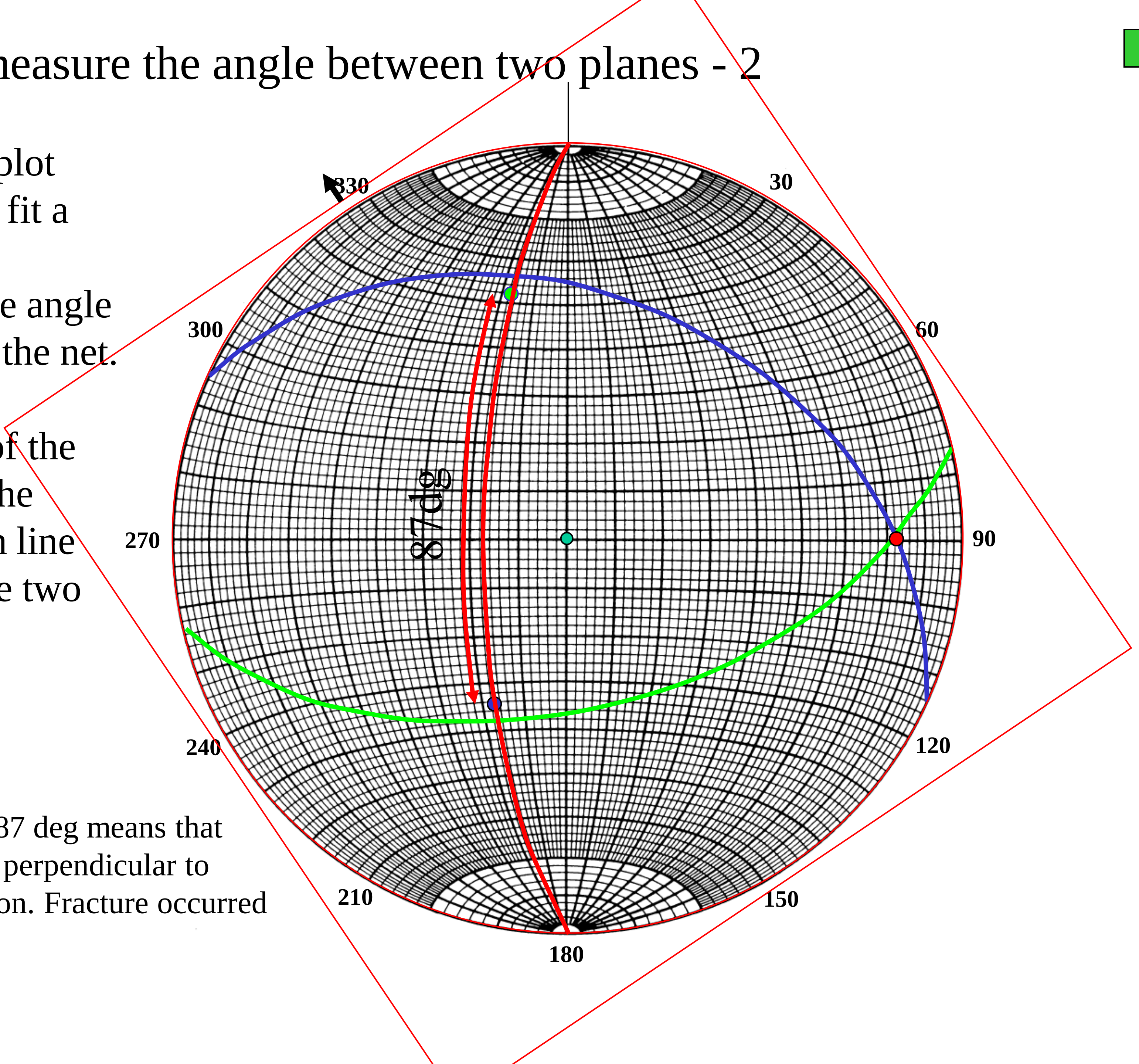
1-
plot the
Pole of each
plane (GC are
Not mandatory)



How to measure the angle between two planes - 2

Rotate the plot
Until poles fit a
GC
Measure the angle
directly on the net.

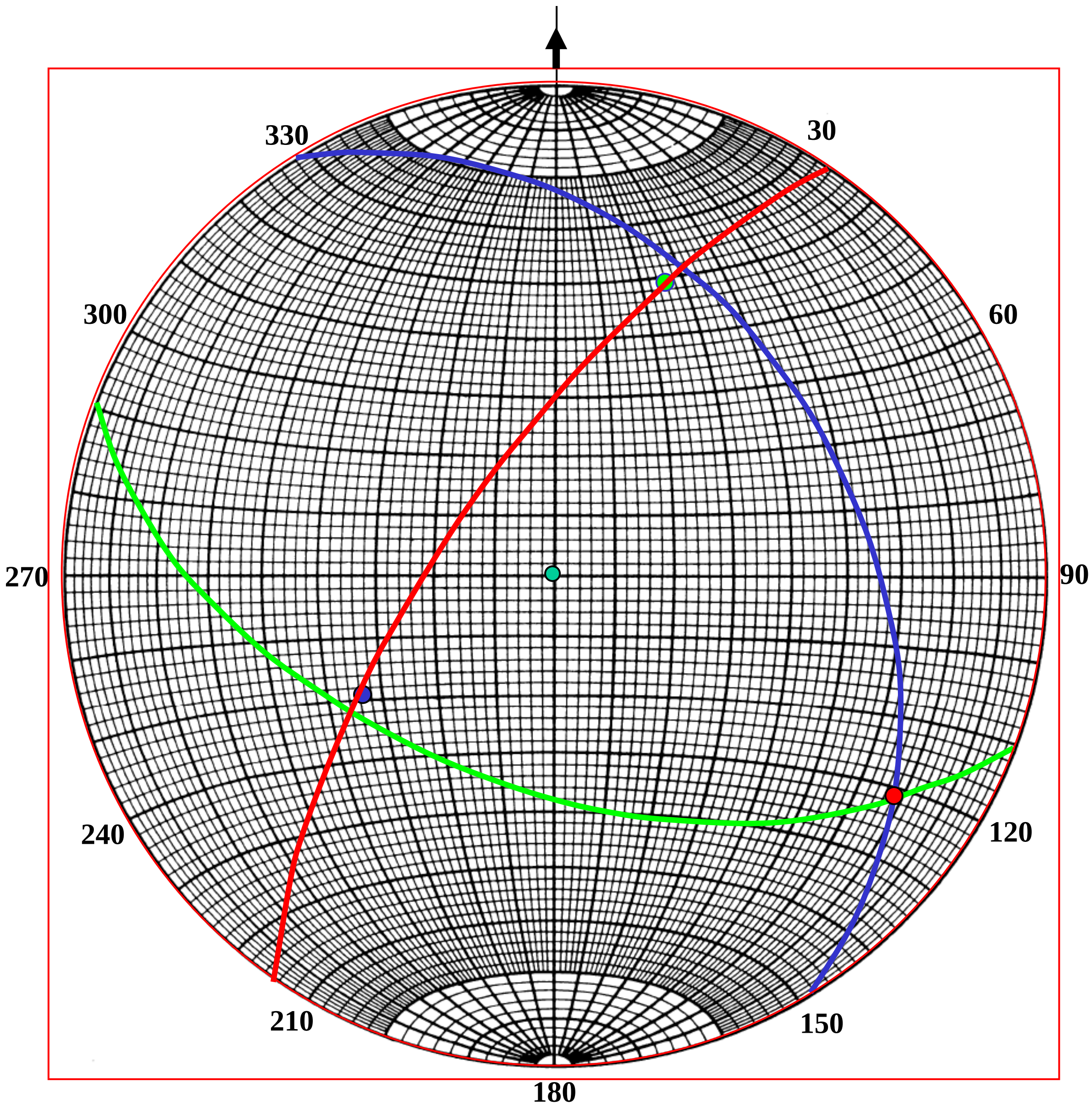
(The pole of the
GC being the
intersection line
between the two
Planes)



The angle by 87 deg means that
the fracture is perpendicular to
the stratification. Fracture occurred
prior to tilting

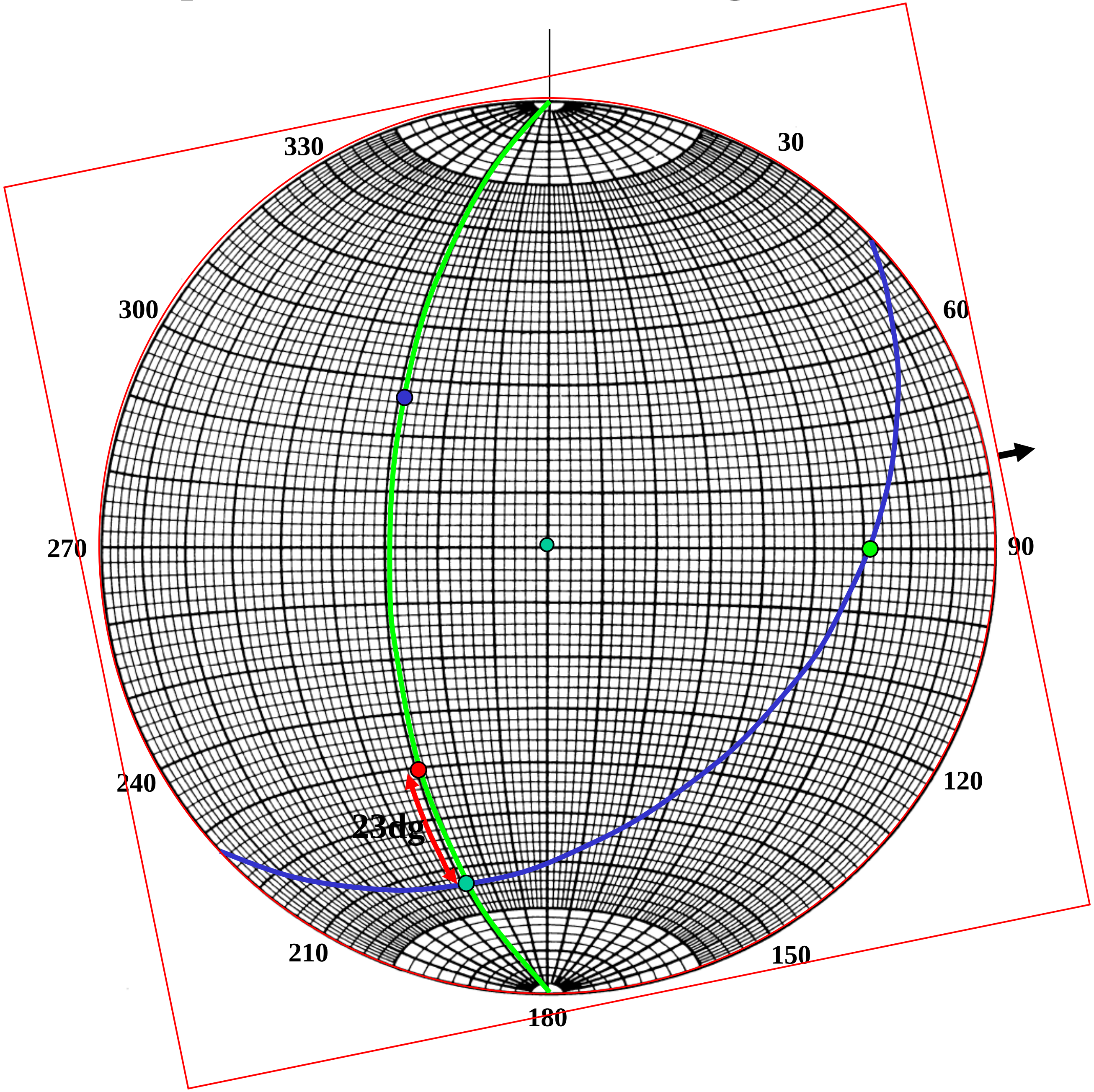
How to measure the angle between two planes - 3

Back to the initial position



How to project a line on a plane and measure the angle between them -1

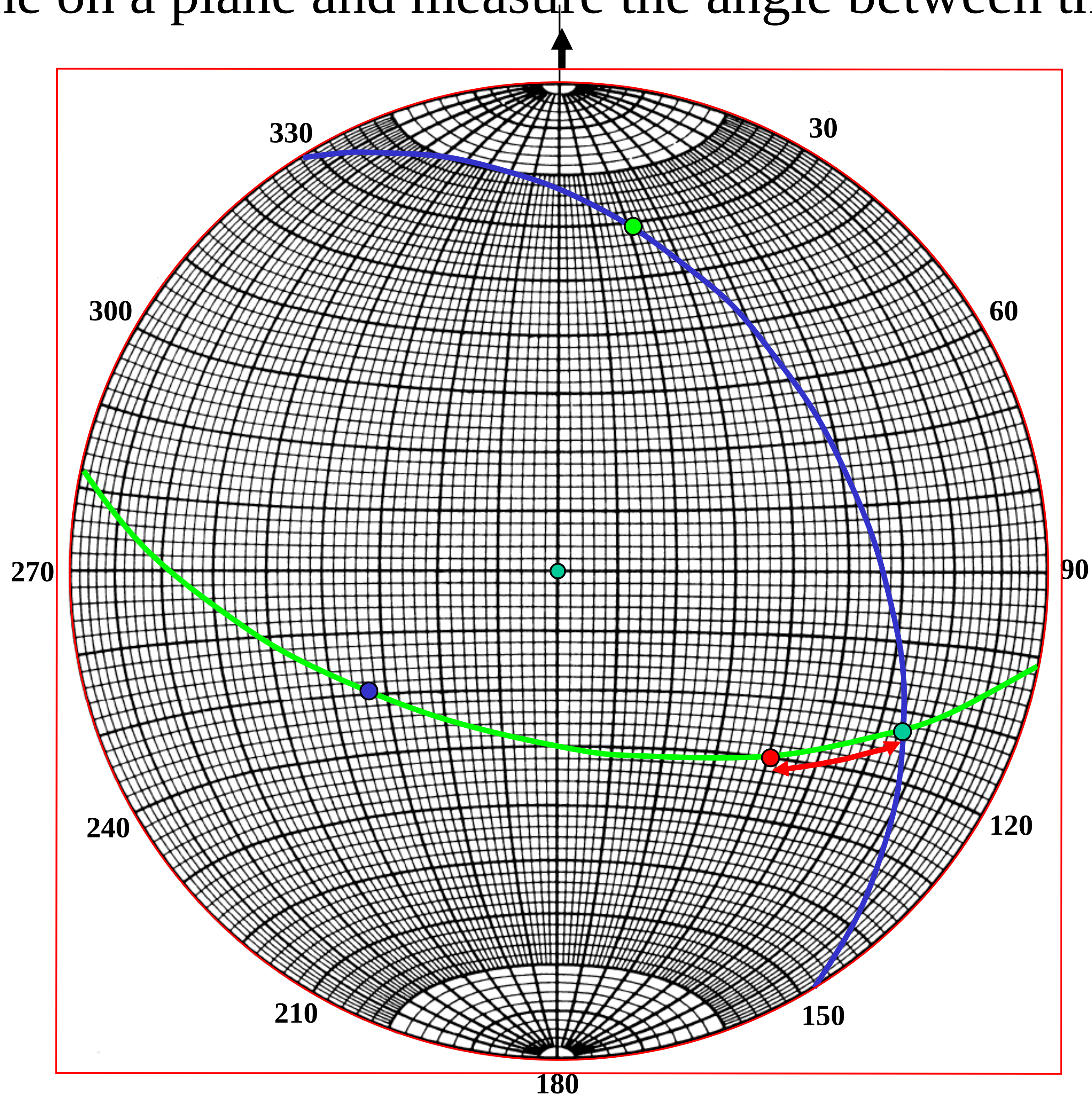
Rotate until the line
and the pole of
the plane fit a GC
The intersection
of the two GC
corresponds to
the projection of the
line in the plane.
Read directly the
angle on the GC



How to project a line on a plane and measure the angle between them 2

Back to the

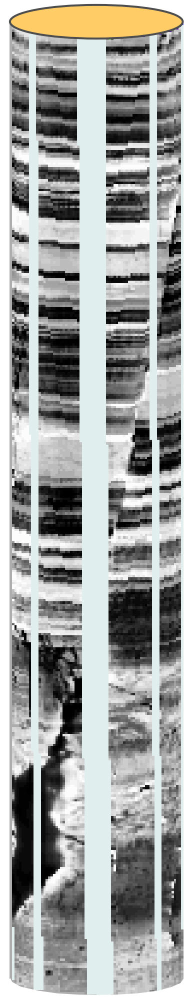
initial position

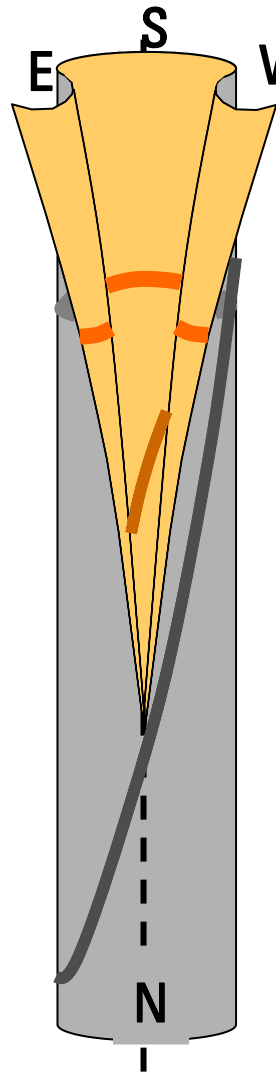


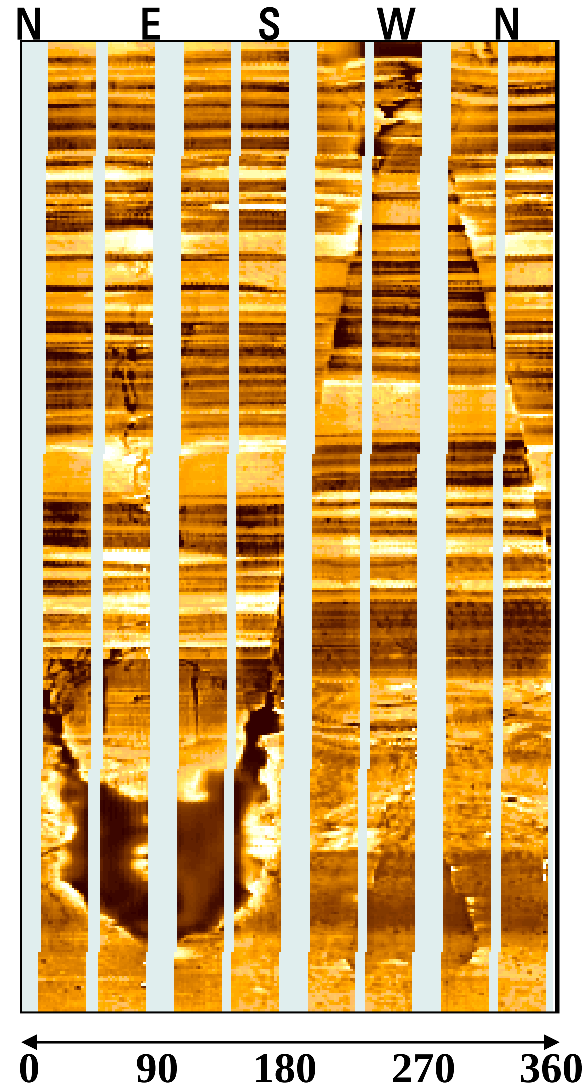
Apparent azimuth to orient features at the borehole wall

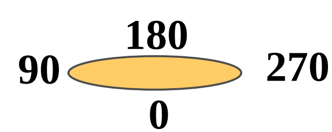
Orienting a feature on an unrolled borehole image, is done using an apparent azimuth. This is an angle measured in the plane perpendicular to the borehole axis relatively to a chosen reference.

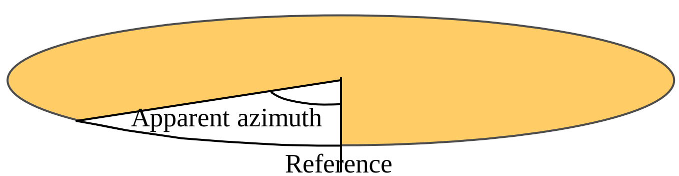
In a vertical well the reference is usually the North direction











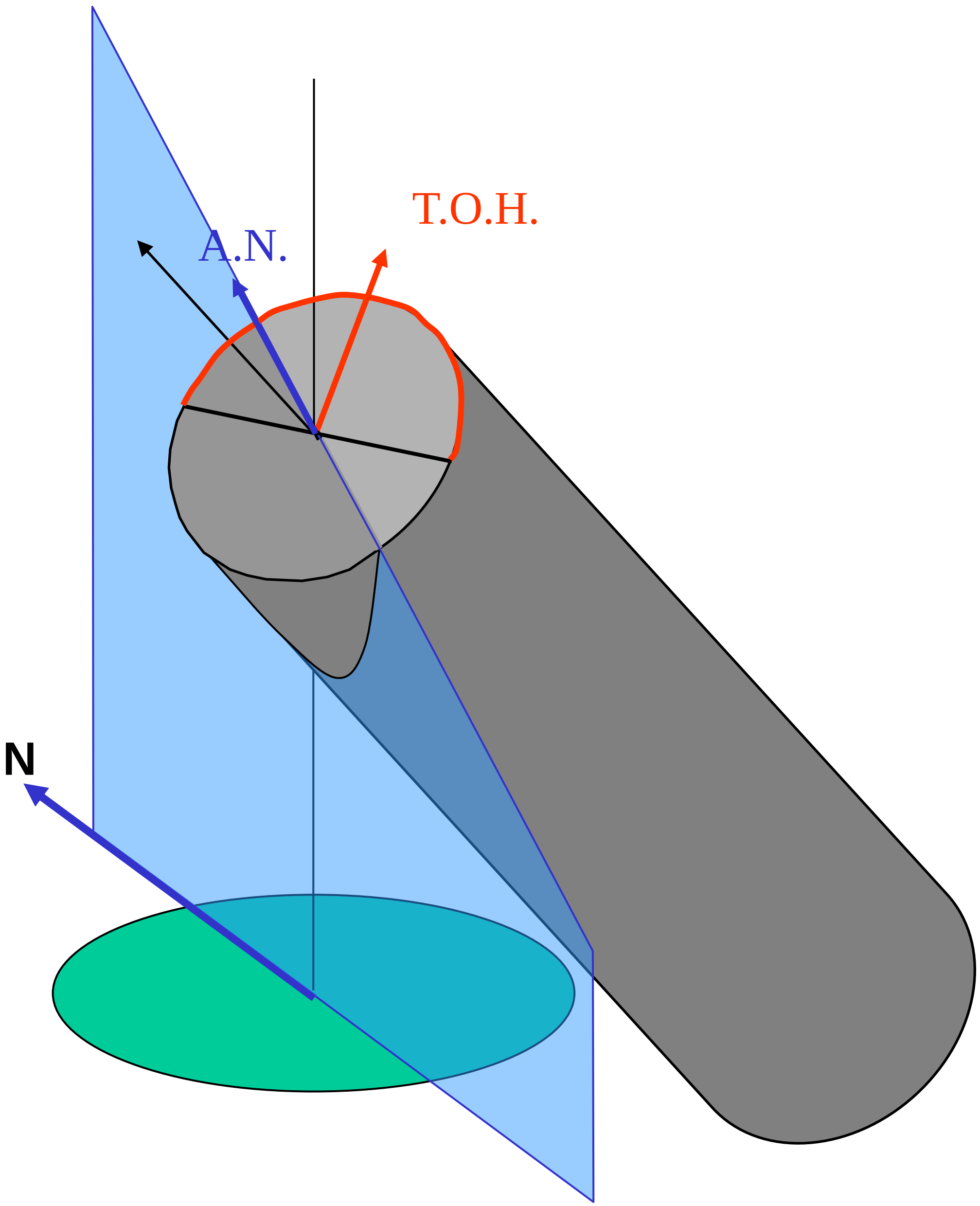
Reference Apparent North or Top Of Hole - 1

In a deviated well the apparent azimuth is an angle measured in the plane perpendicular to the borehole axis, relatively to a chosen reference.

there is two possible references:

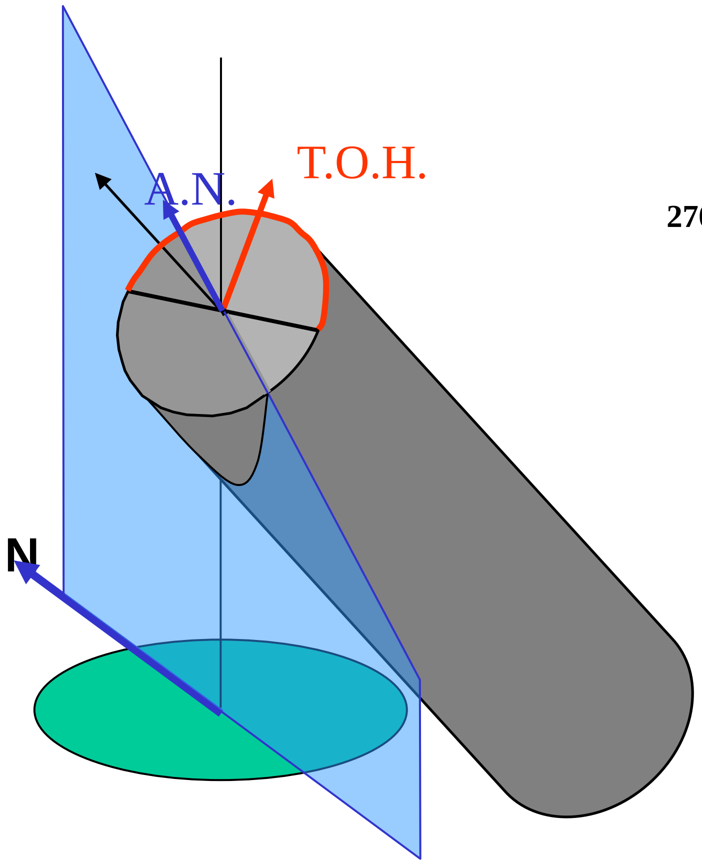
Top of hole: the top intersection point between the borehole wall and the most dipping line in the plane perpendicular to the borehole axis.

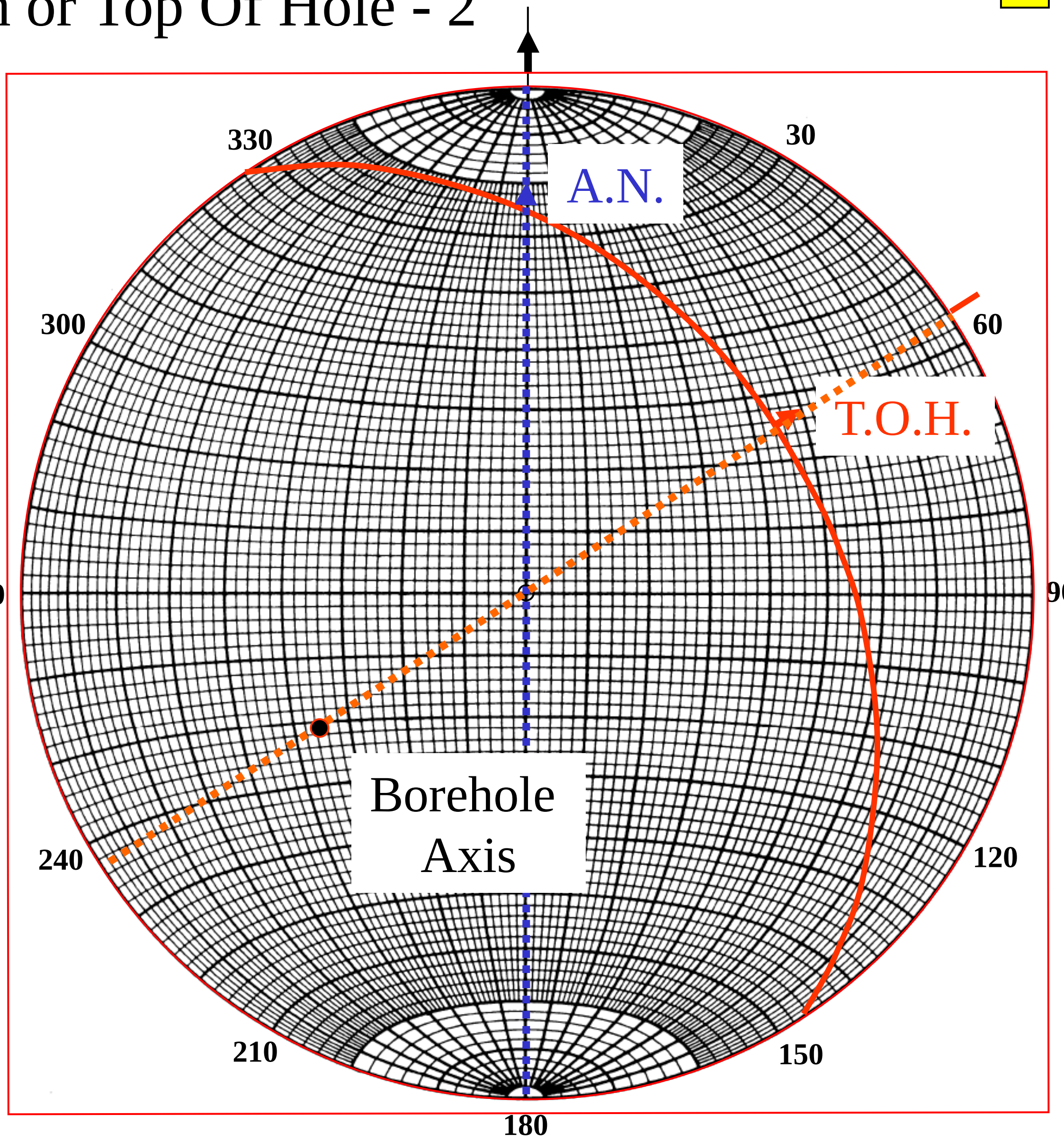
Apparent North: the intersection line between the plane perpendicular to the borehole axis and the vertical plane striking N-S



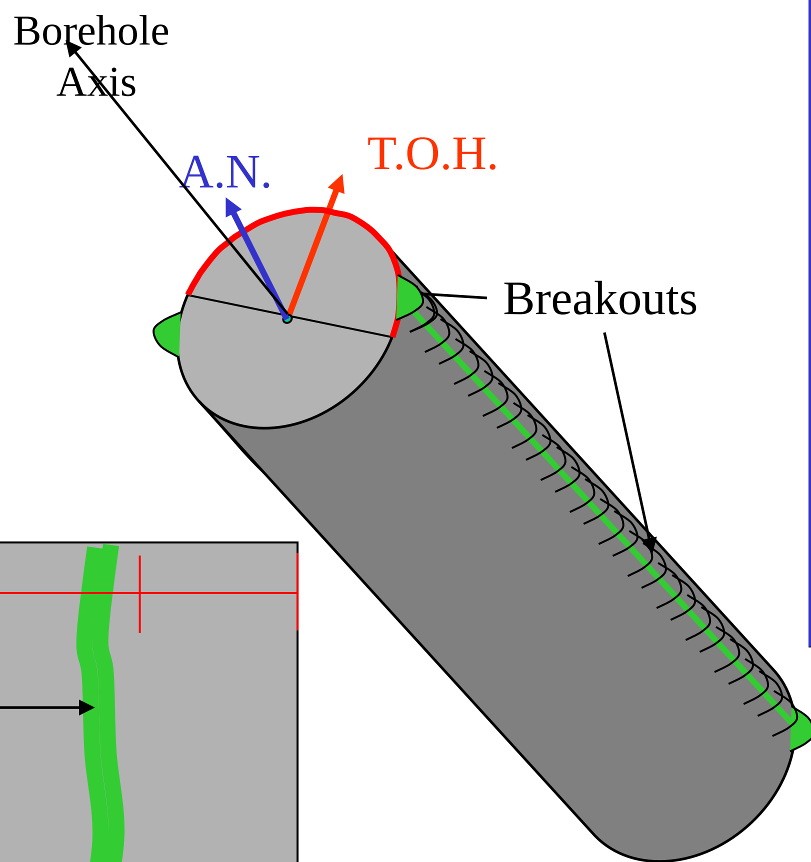
Reference Apparent North or Top Of Hole - 2

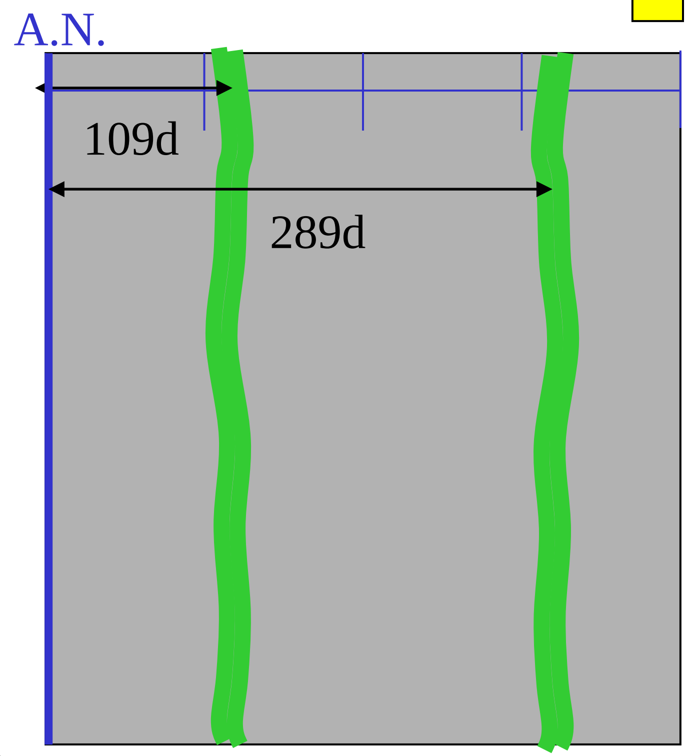
On a Schmidt Net

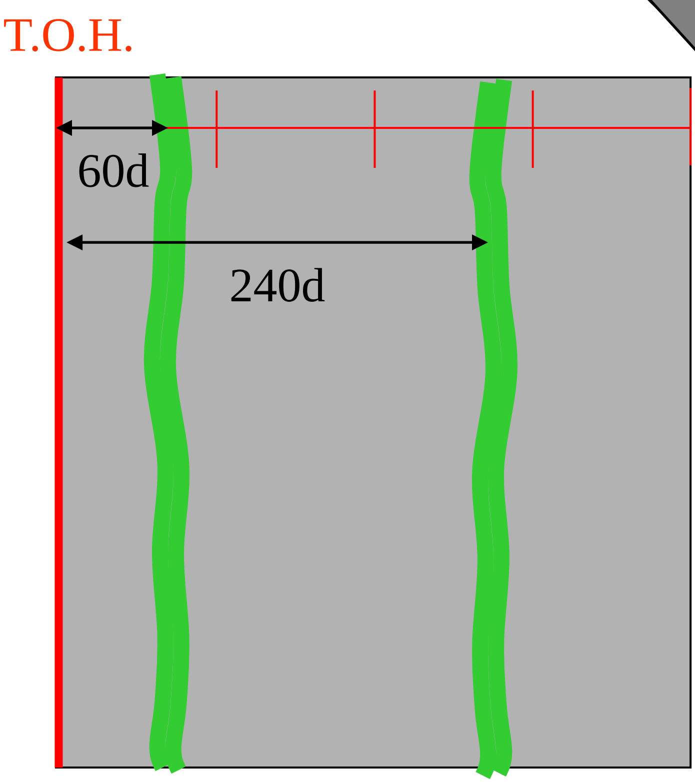




True vs Apparent azimuths -1







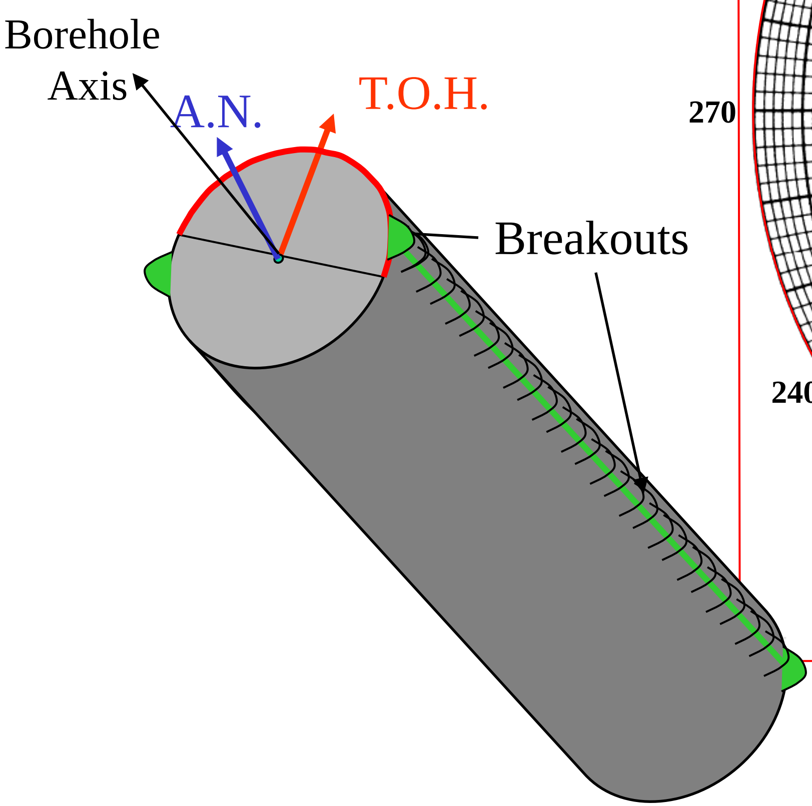
On the unrolled image of the borehole wall, a feature, such as a breakout is oriented relatively to the Top Of Hole or to the Apparent North. What is the true Azimuth?

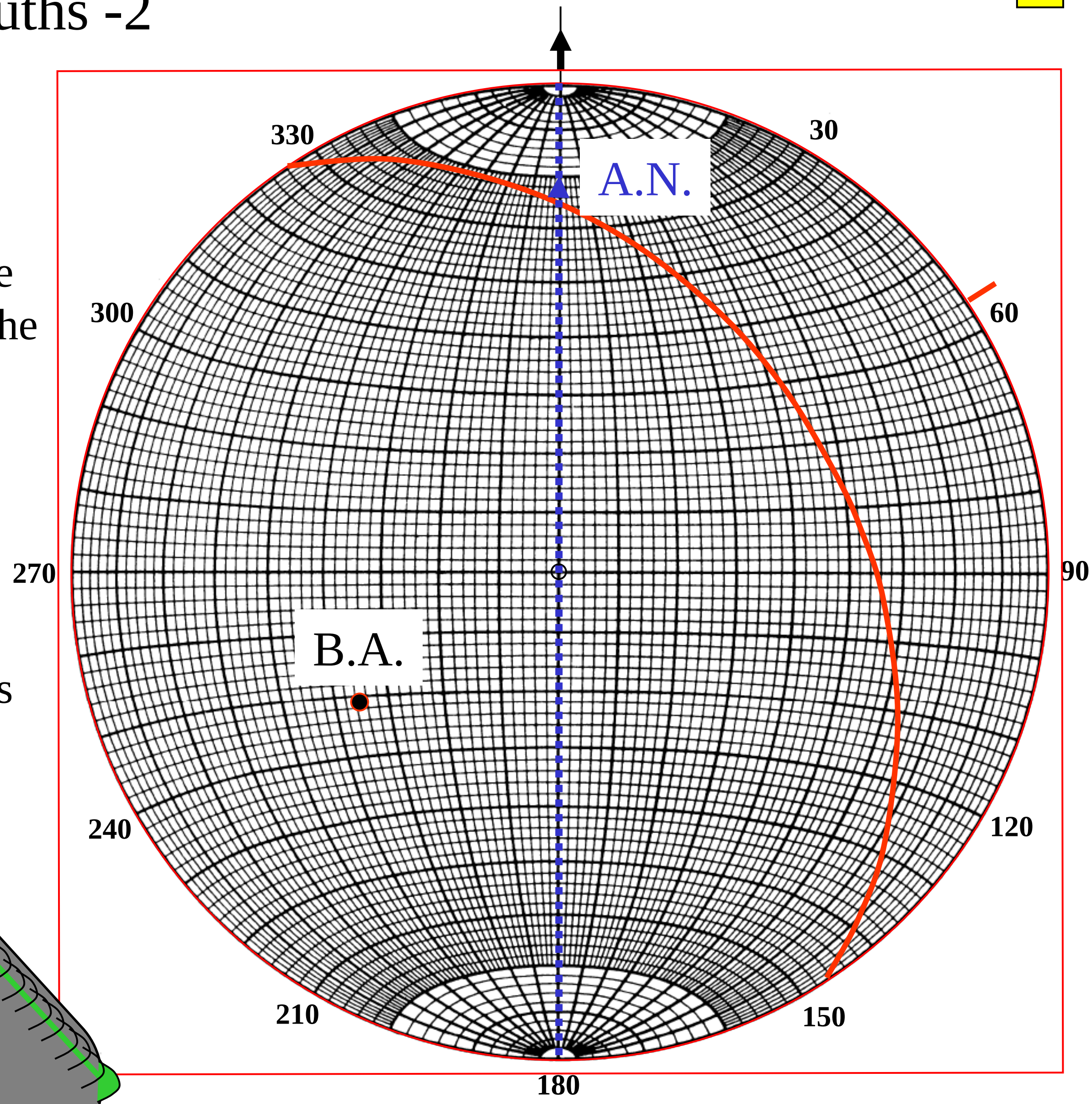
In this particular example the well deviation is 40 to N-56
And the BO are oriented 60-240 TOH or 109-289 AN.

True vs Apparent azimuths -2

Plot the Borehole Axis and the corresponding G.C. of the well deviated: 40 to N-56

Plot the Apparent North, that is the intersection between the GC and the N-S vertical plane.





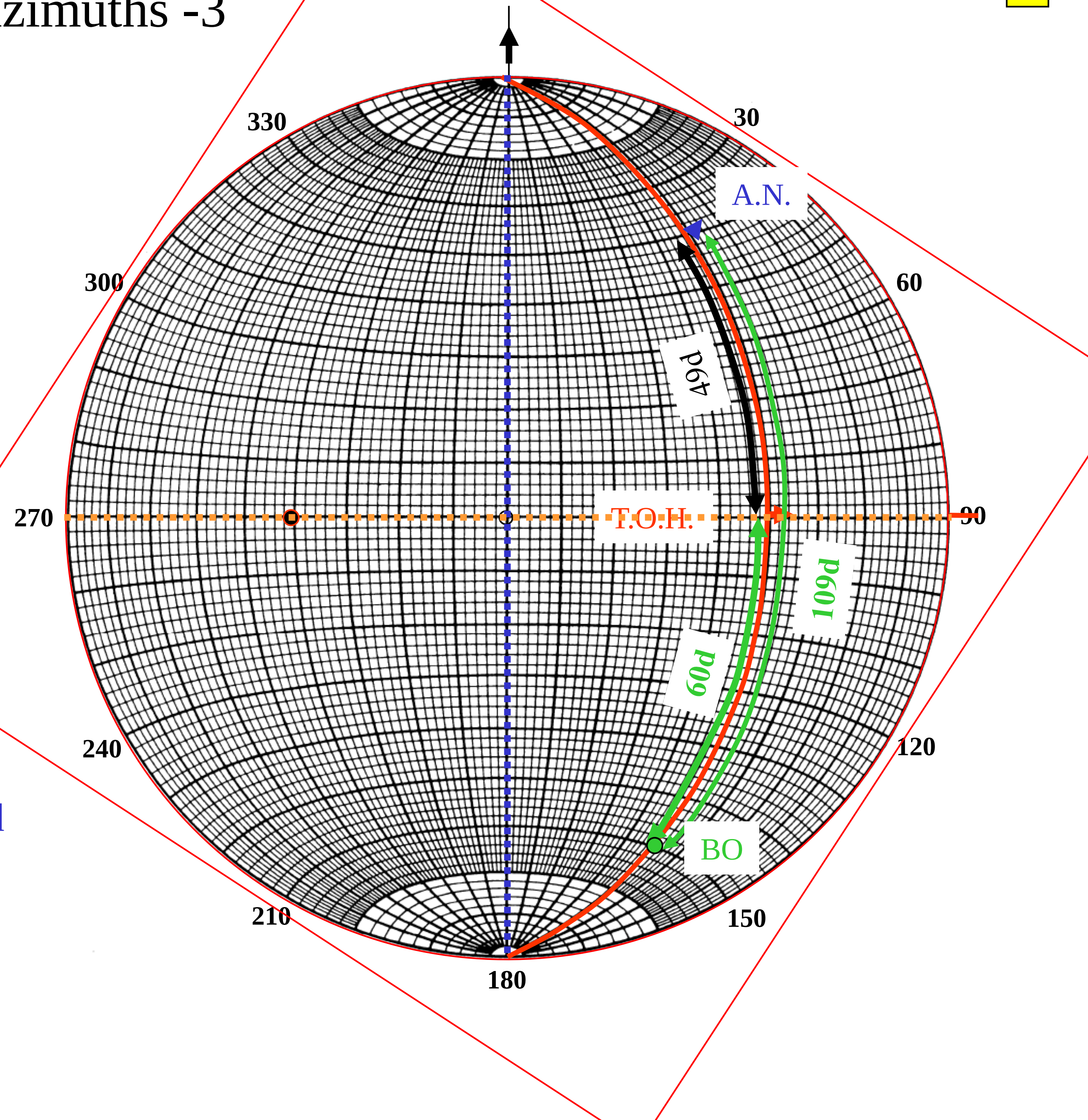
True vs Apparent azimuths -3

Rotate the GC to fit a GC of the net;

Plot the T.O.H. that is the intersection of the GC with the vertical plane passing through the well axis

Measure the angles between the BO and the references Apparent North and T.O.H.

In this particular example,
BO_Azi_T.O.H. = 60d
BO_Azi_A.N. = 109d
Azi_T.O.H.=Azi_A.N. – 49d

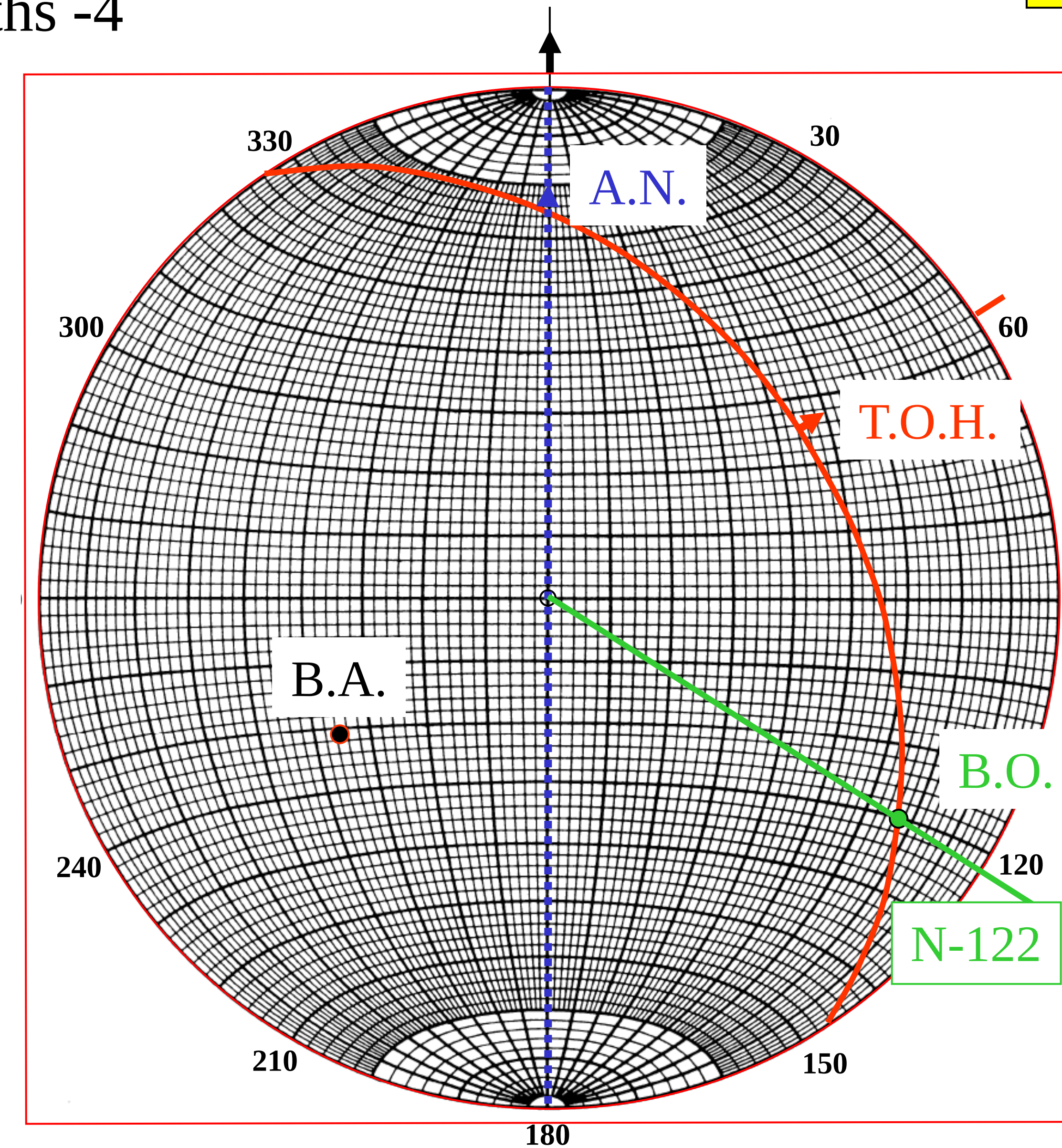


True vs Apparent azimuths -4

When back to the initial position measure the true azimuth of the BO. (N122)
It does not correspond to the azimuth (109) measured with respect to the Apparent North

This is due to the fact that the A.N. azimuth is measured in a plane that is not horizontal

p.s. In BorStress, use the azimuth either TOH or AN (i.e. the value given in Borview by the function "show value at cursor"). Do not use the true azimuth as it is boring to compute this value.



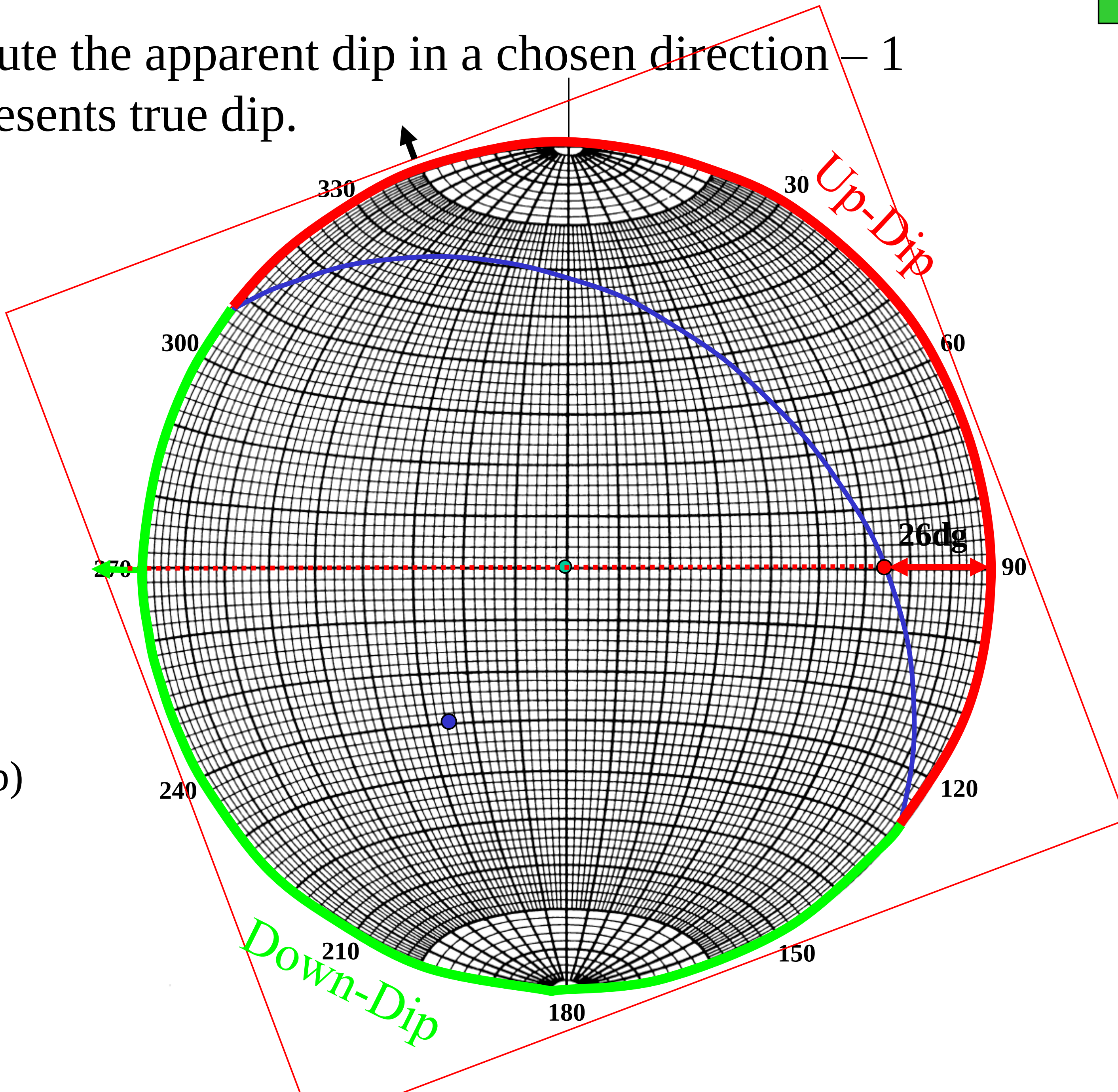
B.O. true azimuth: N122

How to compute the apparent dip in a chosen direction – 1

Blue GC represents true dip.

Put a tick at the chosen azimuth (N-290)
Rotate until it is EW
Measure the apparent dip on this axis directly

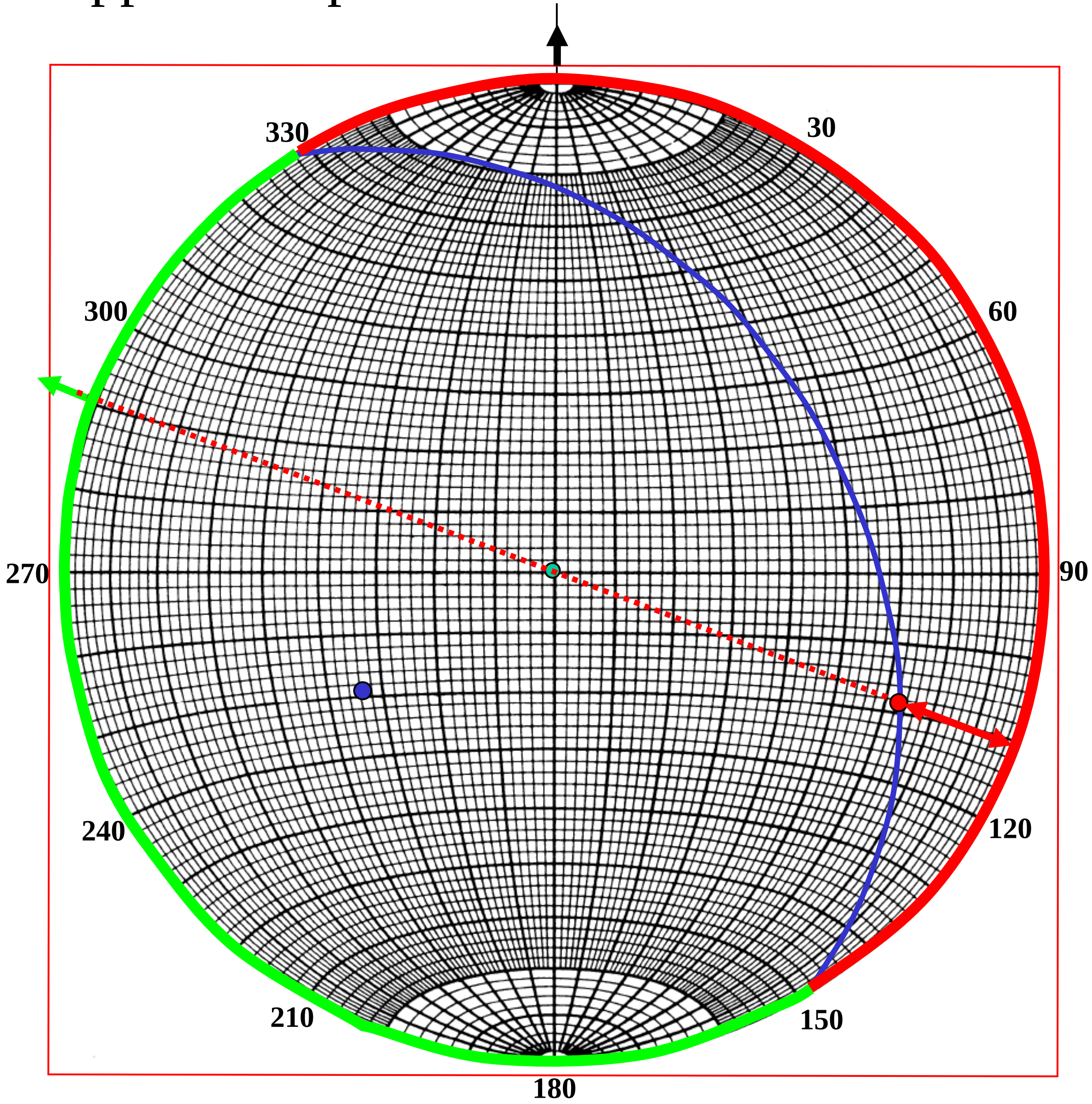
(26 deg Down-dip)



How to compute the apparent dip in a chosen direction - 2

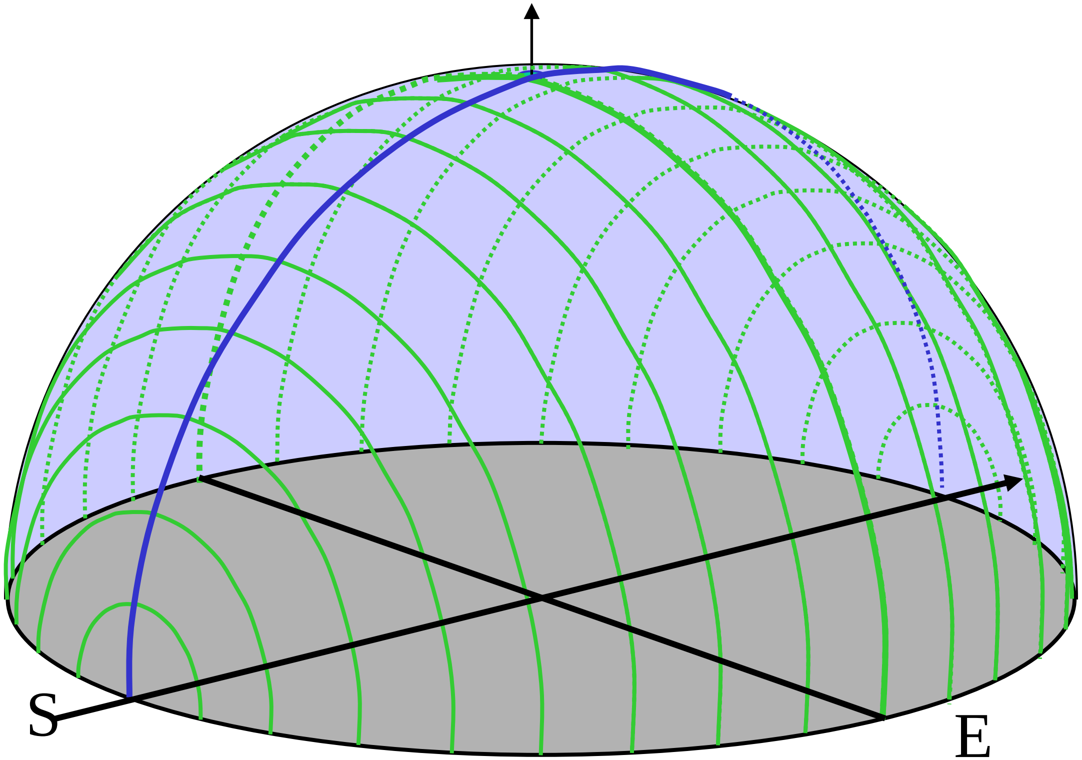
Back to the

initial position



Small Circles

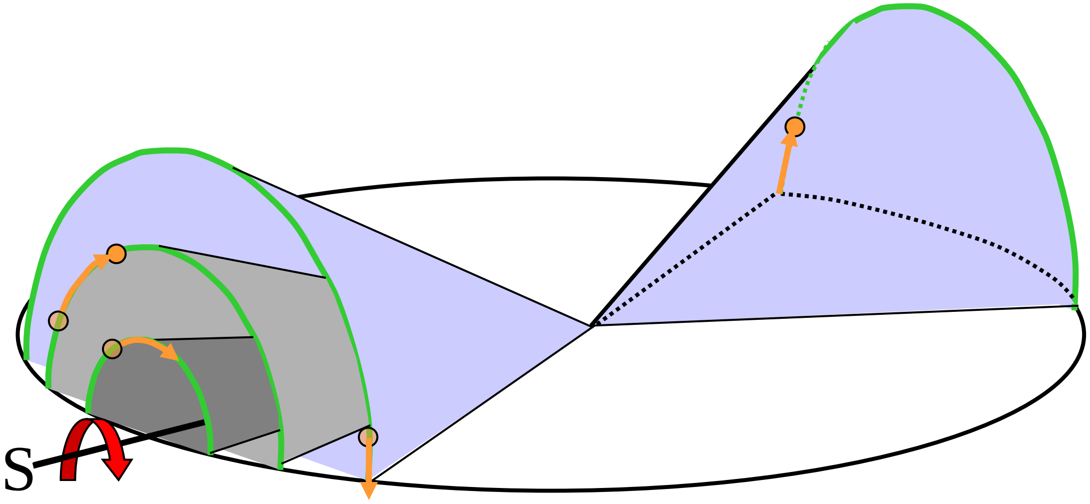
Each small circle corresponds to the intersection between the hemisphere and a cone whose axis is horizontal.

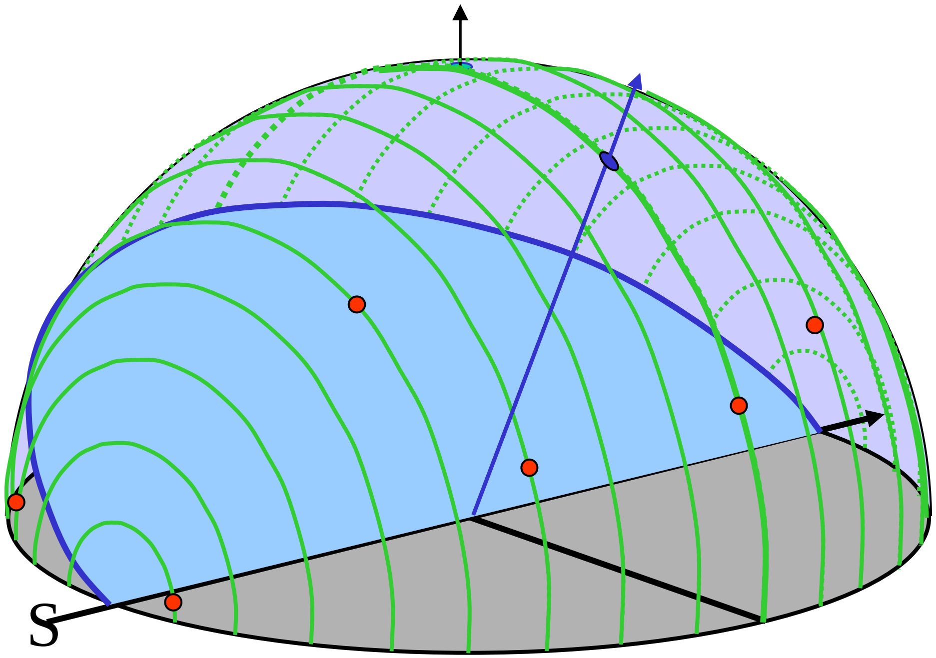


If during rotation, the end of a line exits the chosen hemisphere the other end enters at 180 dg.

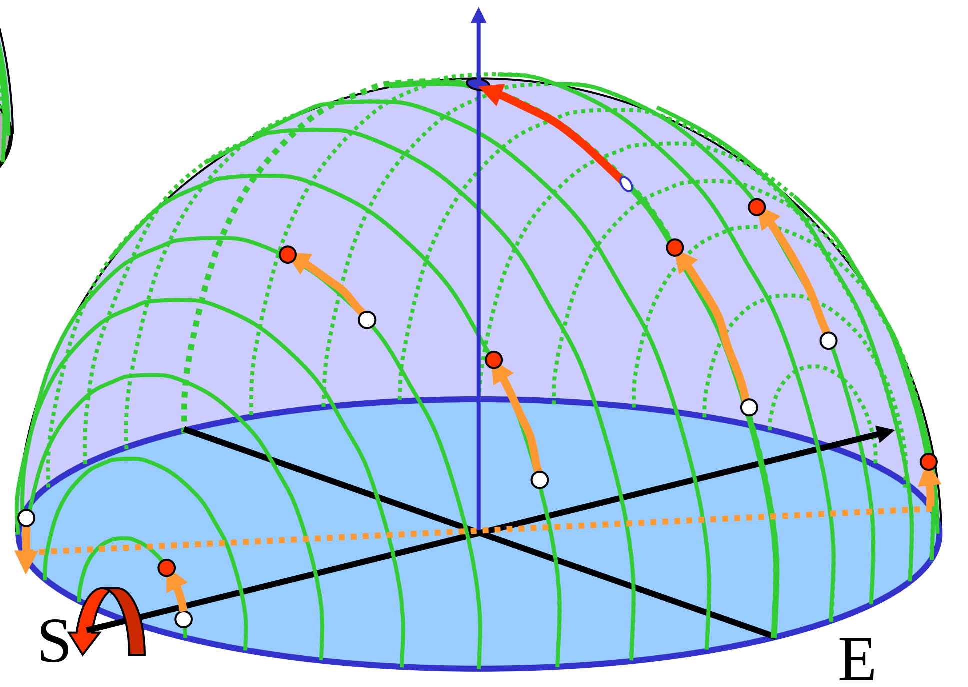
SC are used for:

- rotation in space such as structural dip removal or change from apparent to true dip
- delineating conical folds.





Dip removal using rotation along small circles

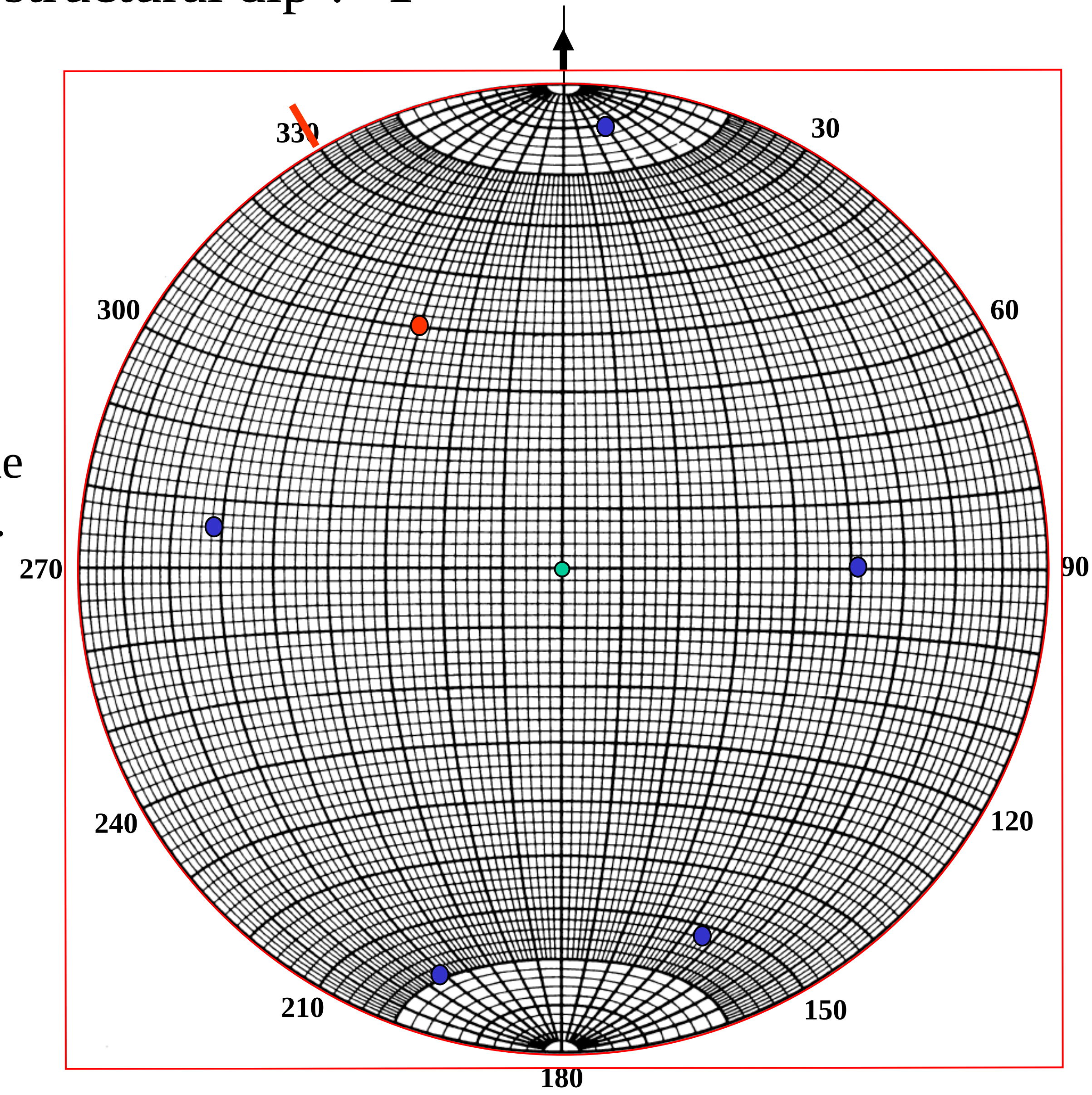


Such rotations can be used to remove the whole structural dip; to remove the effect of a late tilt; to remove the tilt of a fold axis….

How to remove a structural dip ? -1

Ex 49 dg to N-330

Plot the pole of the structural dip and the pole of the planes to be removed.
Red dot is the pole of the structural dip (bedding).
Blue dots are poles to other planes.



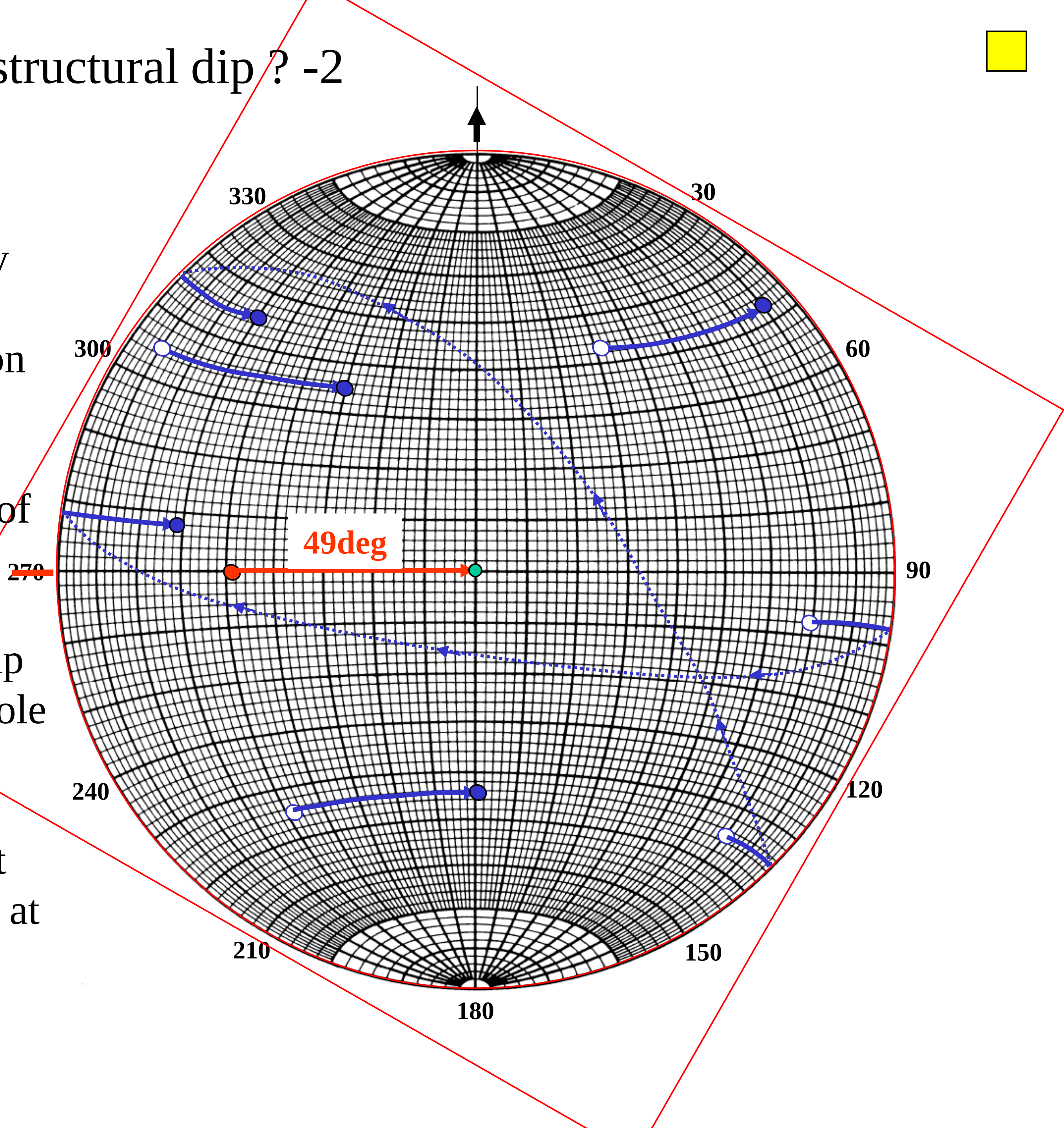
How to remove a structural dip ? -2

Ex 49 dg to N-330

Rotate the transparency until the pole of the structural dip appears on the W-E axis.

Rotate by 49 deg each of the poles on its corresponding small circle. The structural dip is now horizontal, its pole is the center of the net

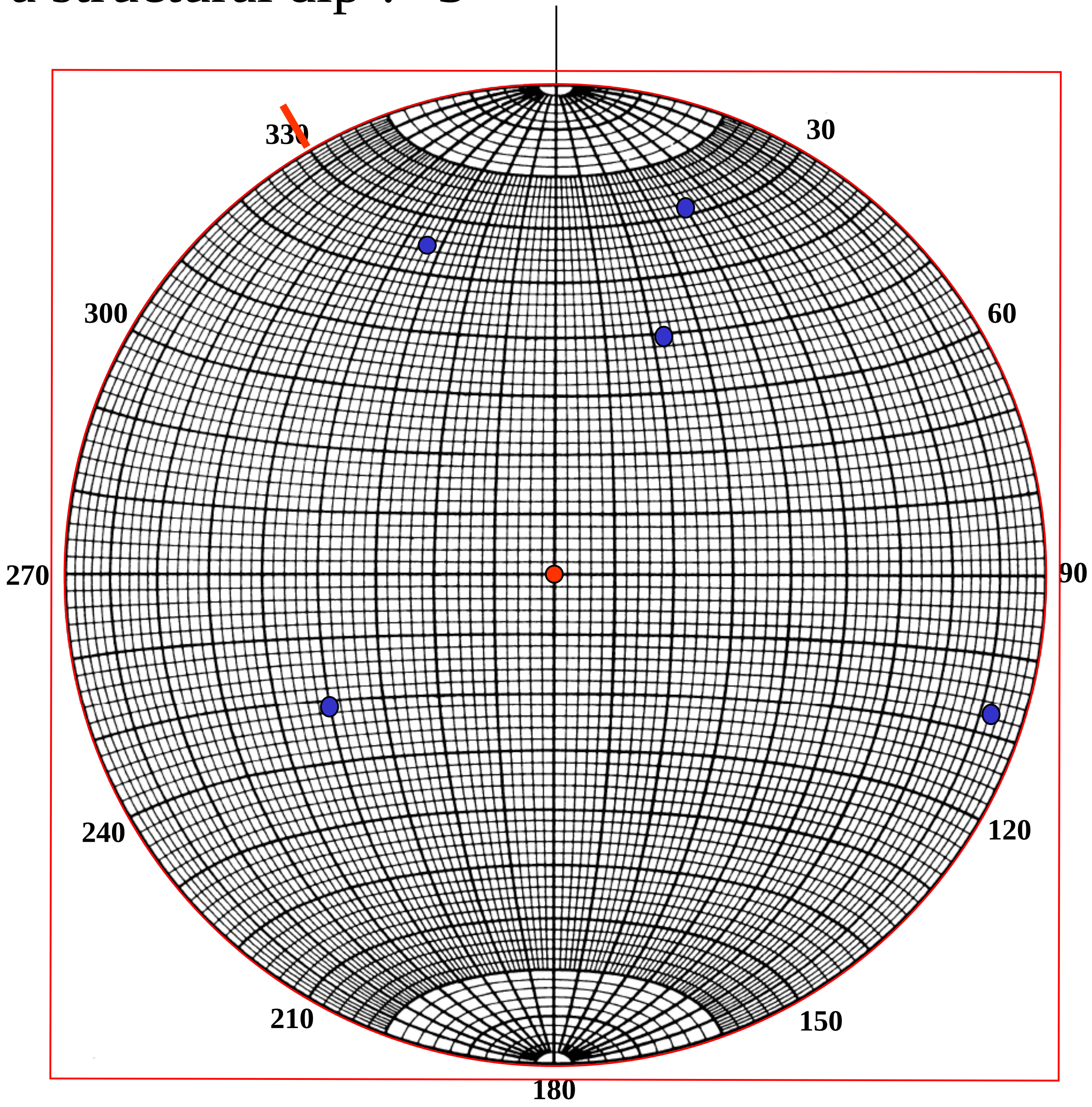
When a pole comes out of the net, it re-appears at 180 deg



How to remove a structural dip ? -3

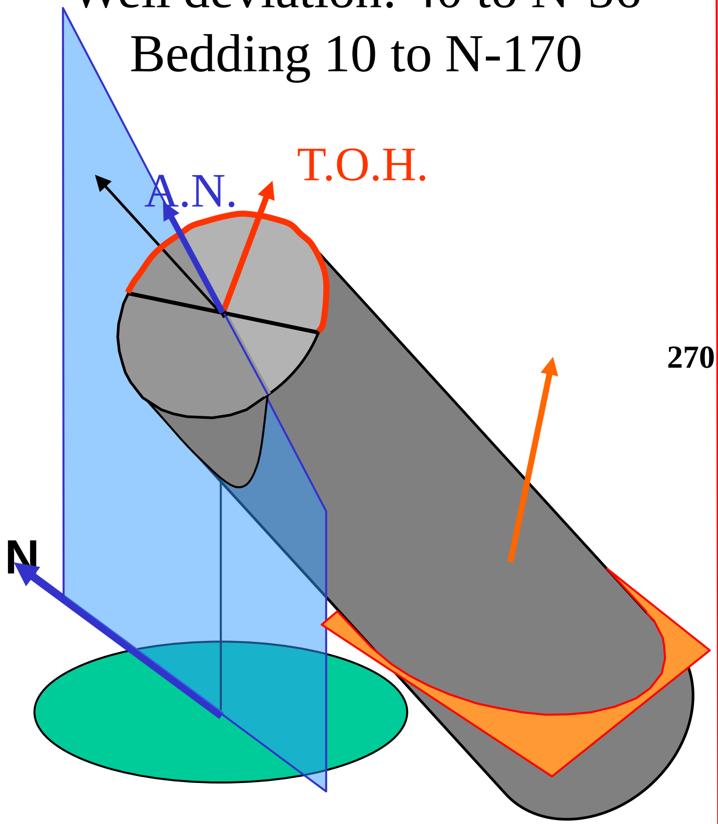
Ex 49 dg to N-330

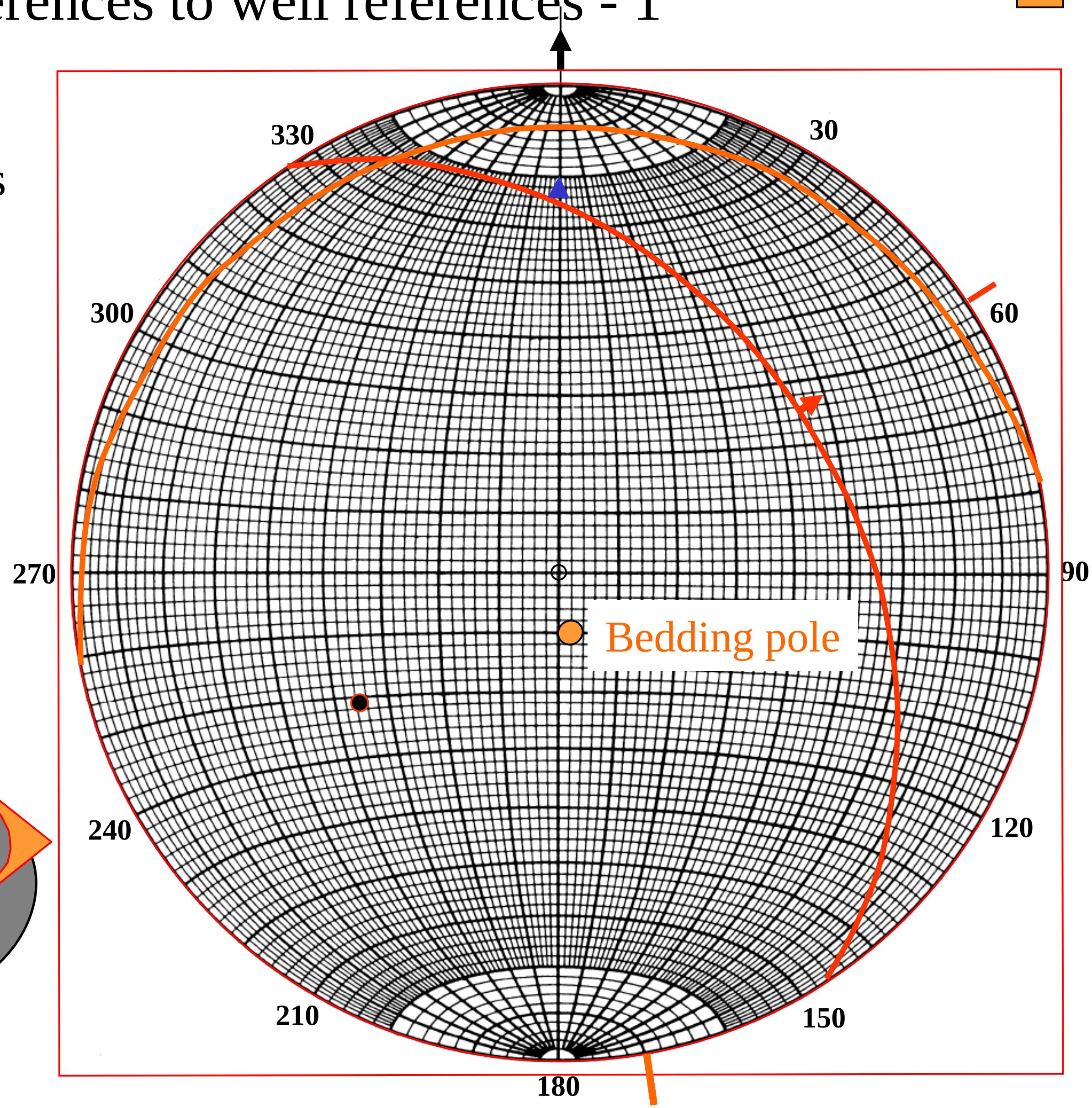
Back to the initial references



From geographic references to well references - 1

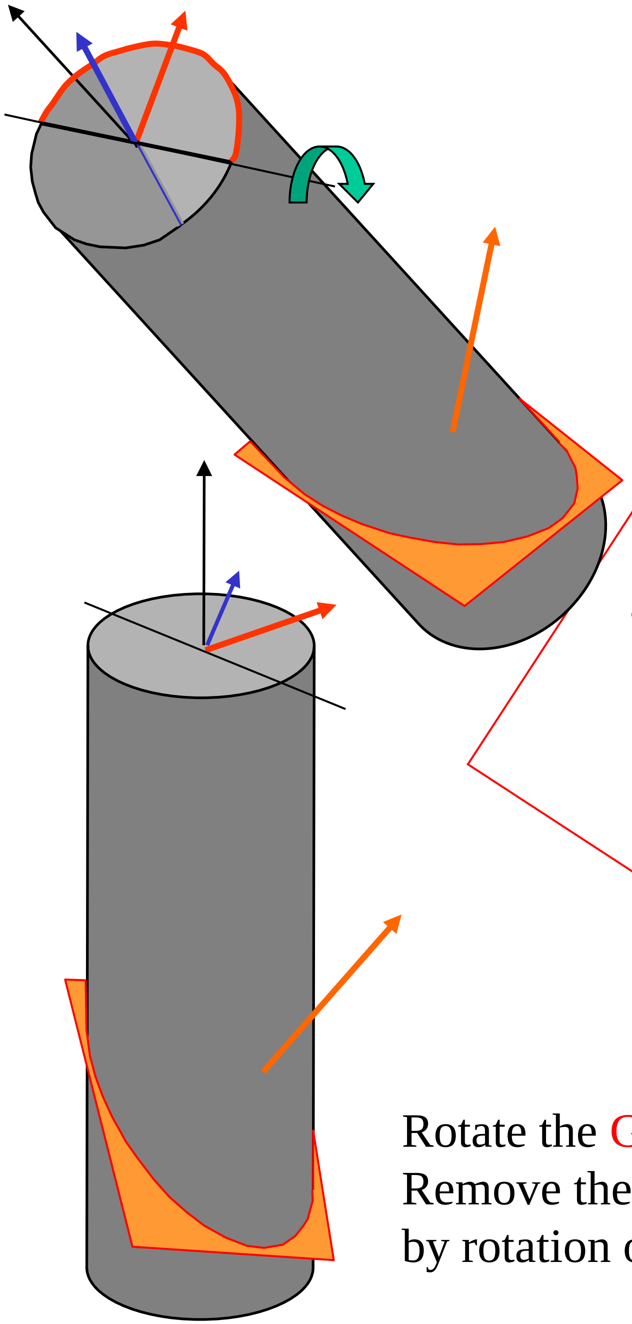
True geographic coordinates
Well deviation: 40 to N-56
Bedding 10 to N-170

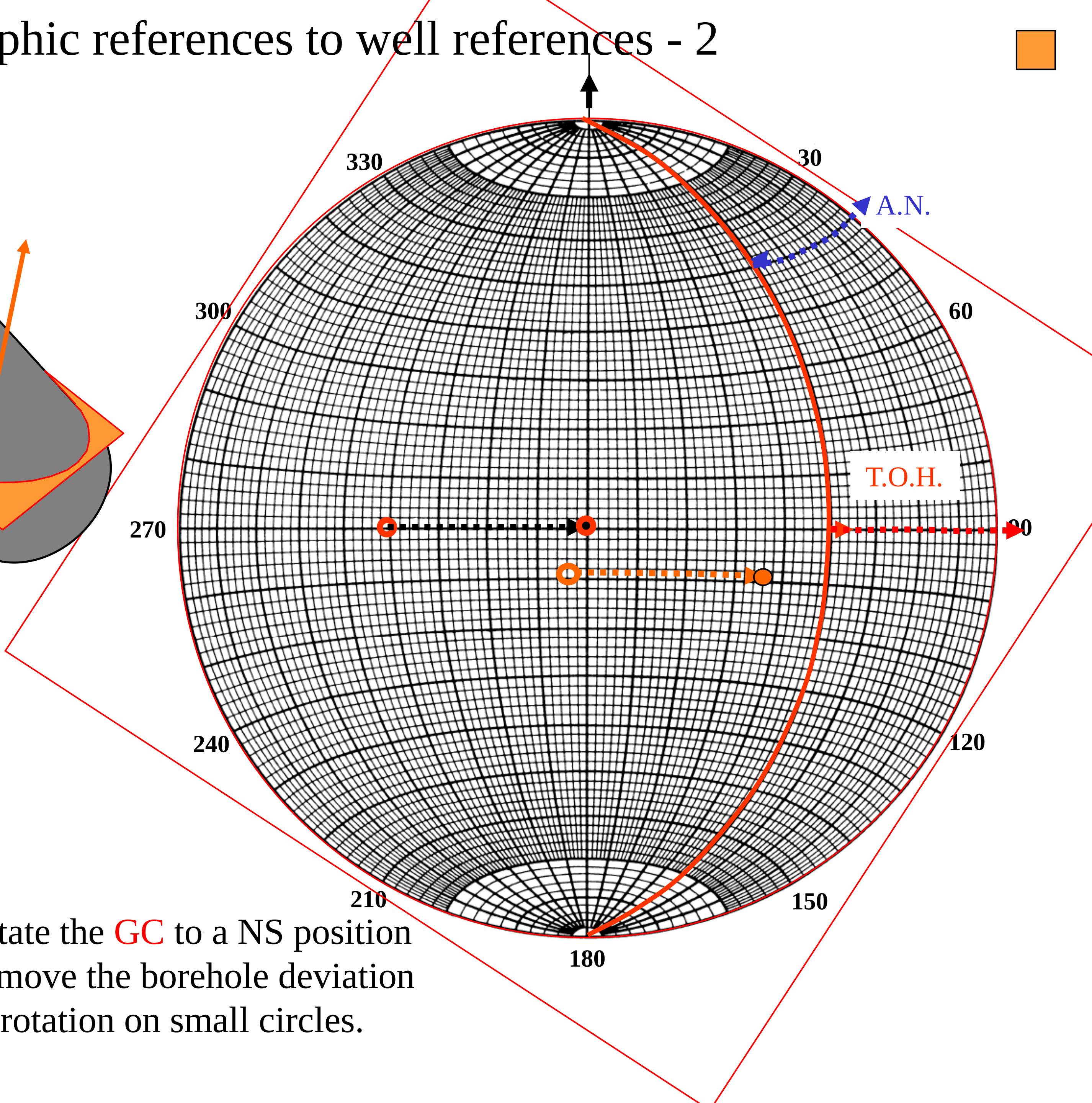




Plot the bedding plane and the plane perpendicular to the borehole axis
Point the Apparent North and the Top Of Hole

From geographic references to well references - 2





Rotate the GC to a NS position
Remove the borehole deviation
by rotation on small circles.

From geographic references to well references - 3

Rotate the chosen reference A.N or T.O.H. on the 0 of the net. This corresponds to the apparent coordinates.

Read the apparent dip

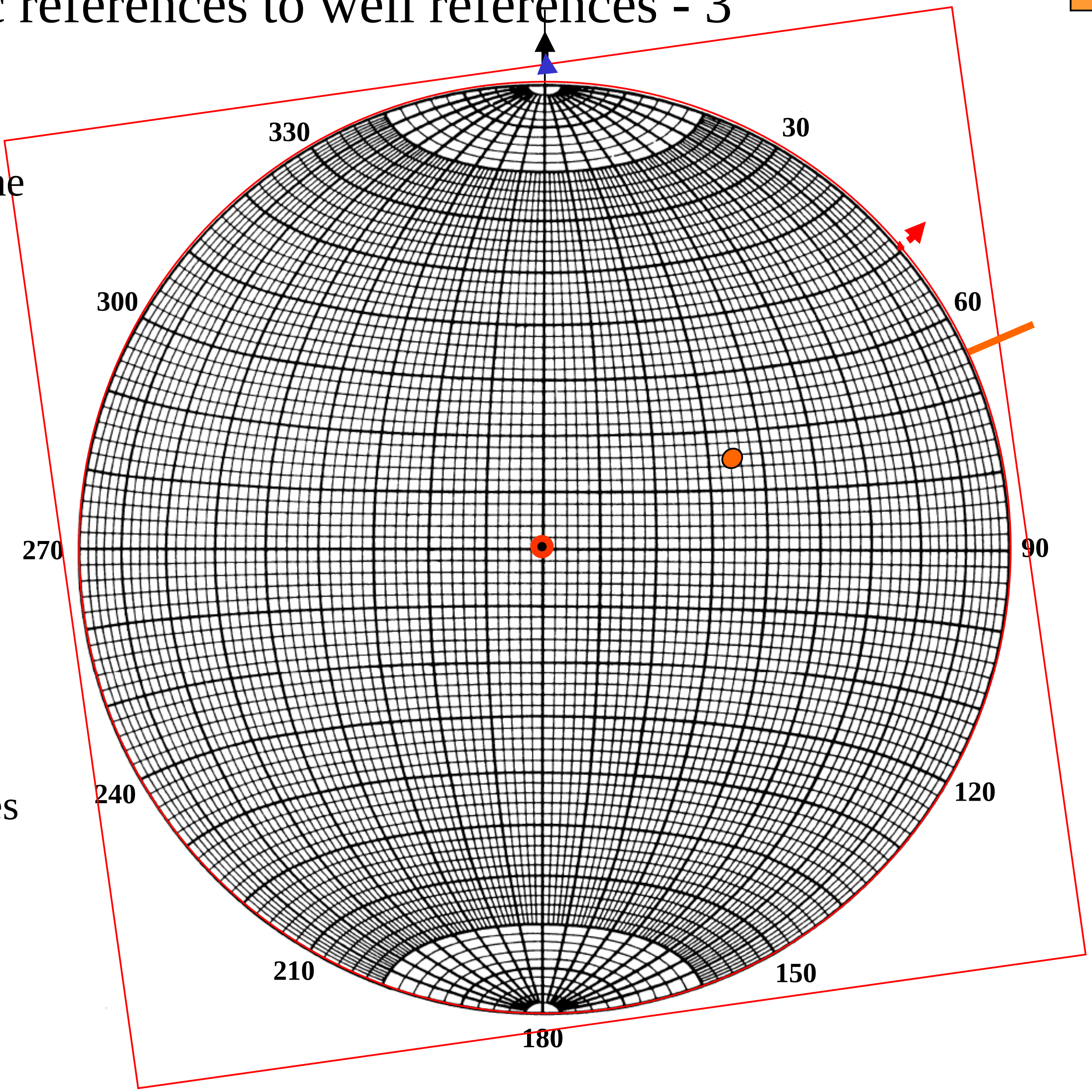
In this particular example bedding is either:

38 to 65 A.N.

Or

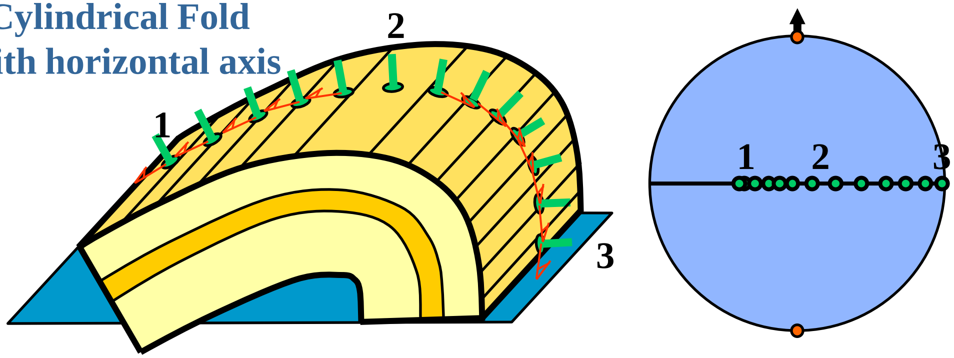
38 to 15 T.O.H.

To determine true references from well references back-perform the same rotations



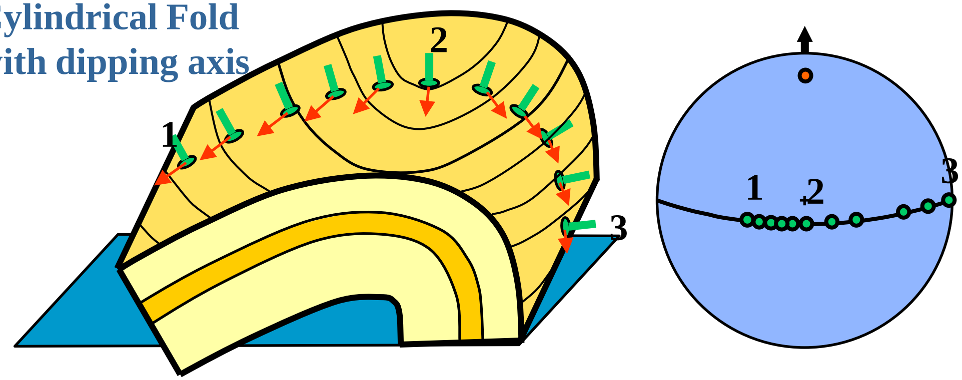
Fold Signatures on a Schmidt Net (UH)

Cylindrical Fold with horizontal axis



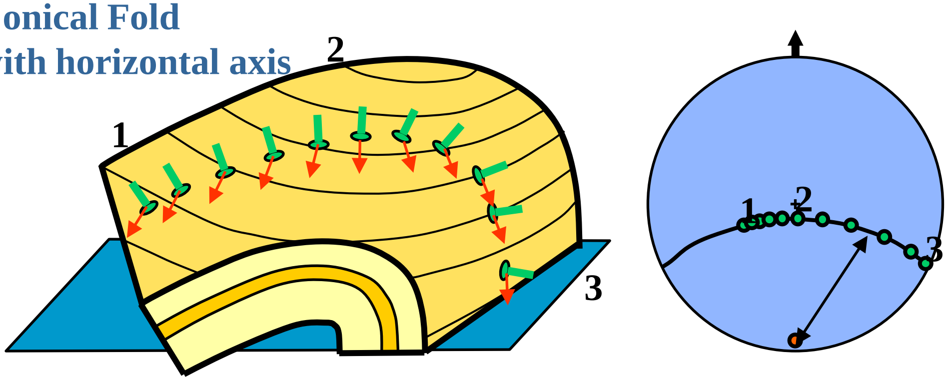
Dips fit a vertical GC, i.e. a diameter of the net. Two azimuths (180 dg apart of each other) are possible

Cylindrical Fold with dipping axis



Dips fit a GC. Azimuths may vary a lot, especially in the hinge zone

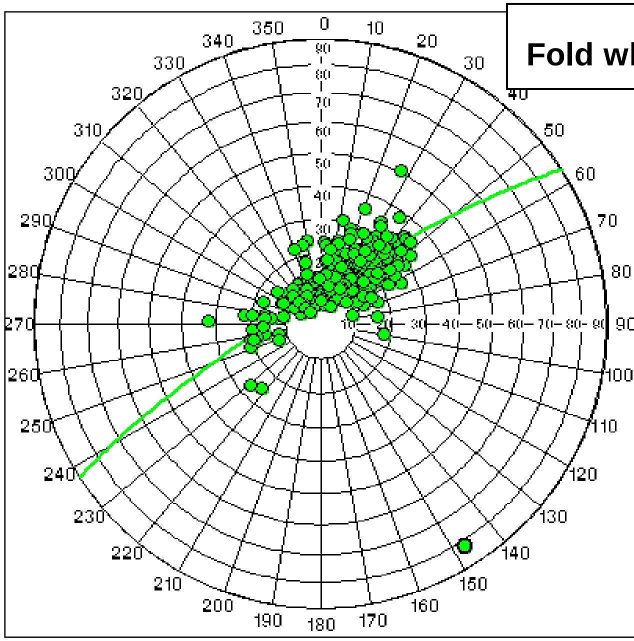
Conical Fold with horizontal axis

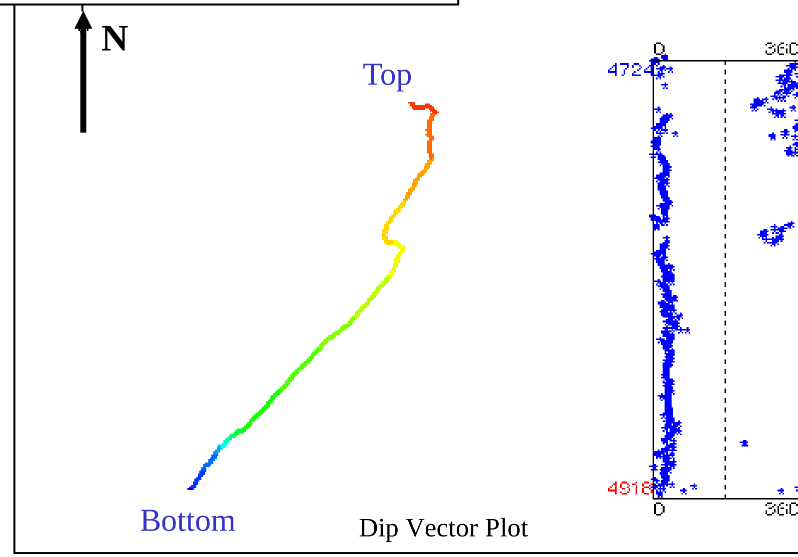


Dips fit a Small Circle whose angular distance to the axis corresponds to the conicity.
Azimuths may vary a lot, especially in the hinge zone

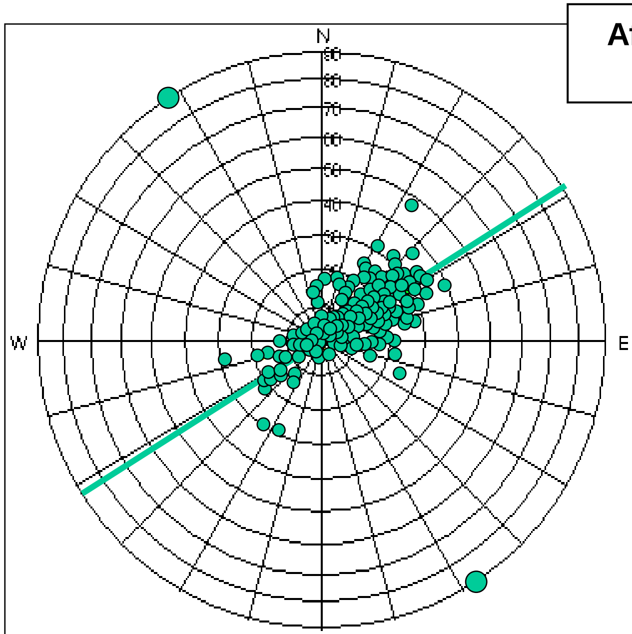
Example of the influence of the axis plunge on the azimuth of dips

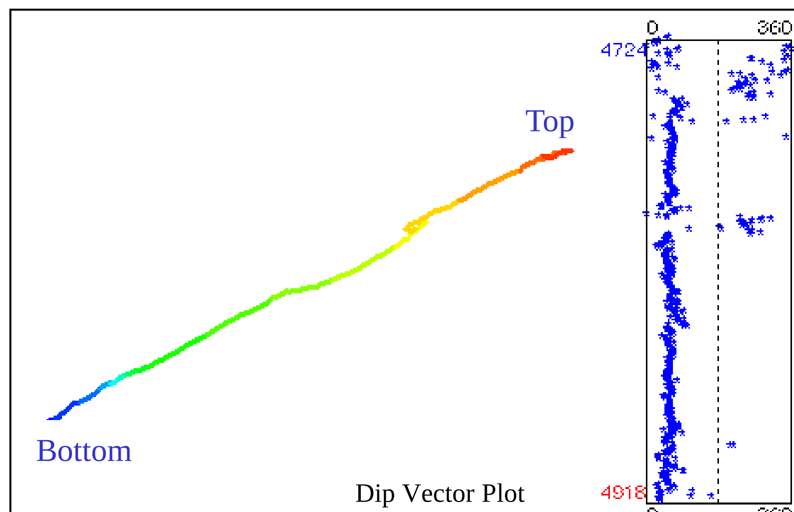
Fold whose axis plunges 8 deg to N-327 (147+180)



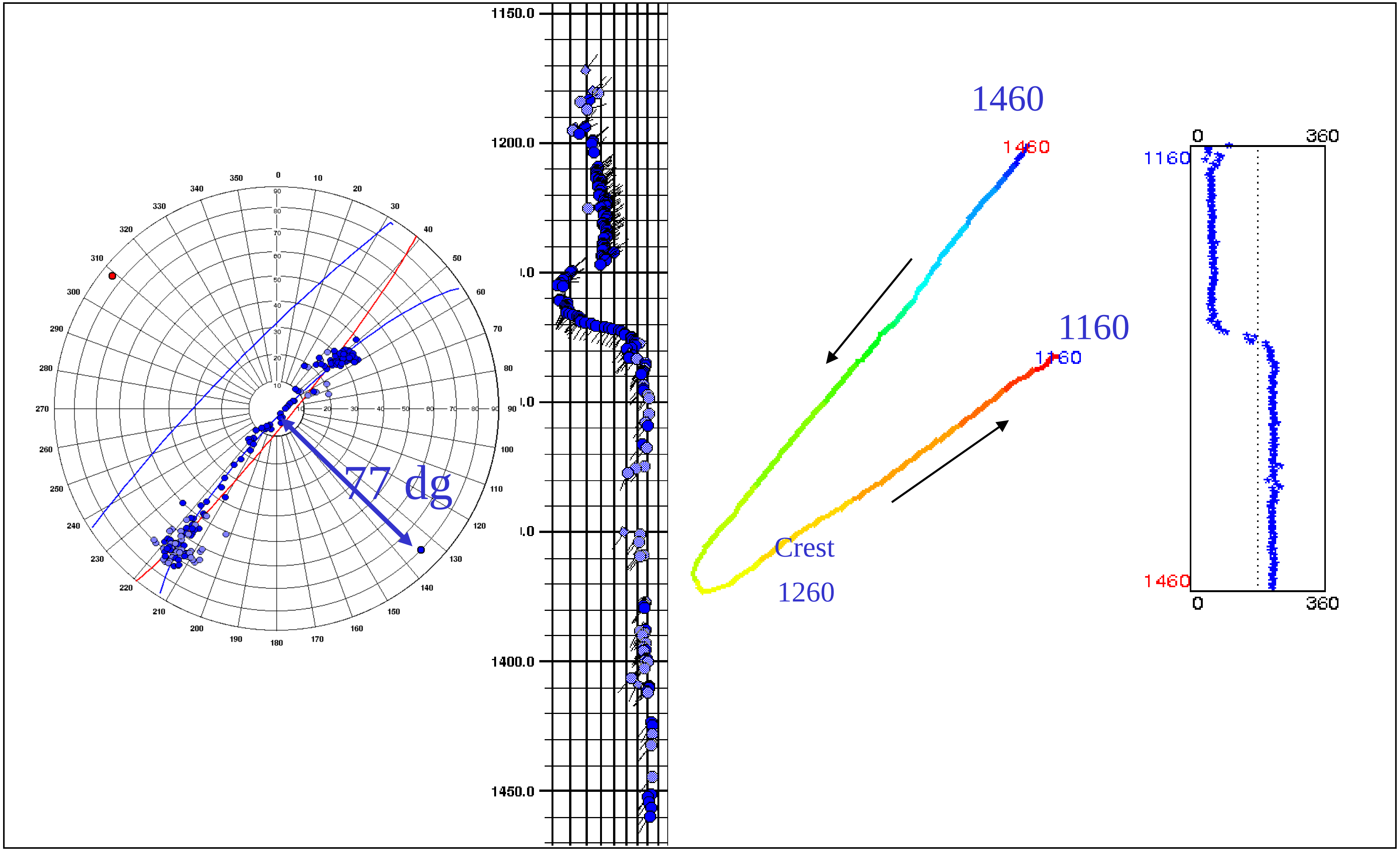


After removal of the plunge of the axis, note how constant is the dip direction. It means that the fold is perfectly cylindrical



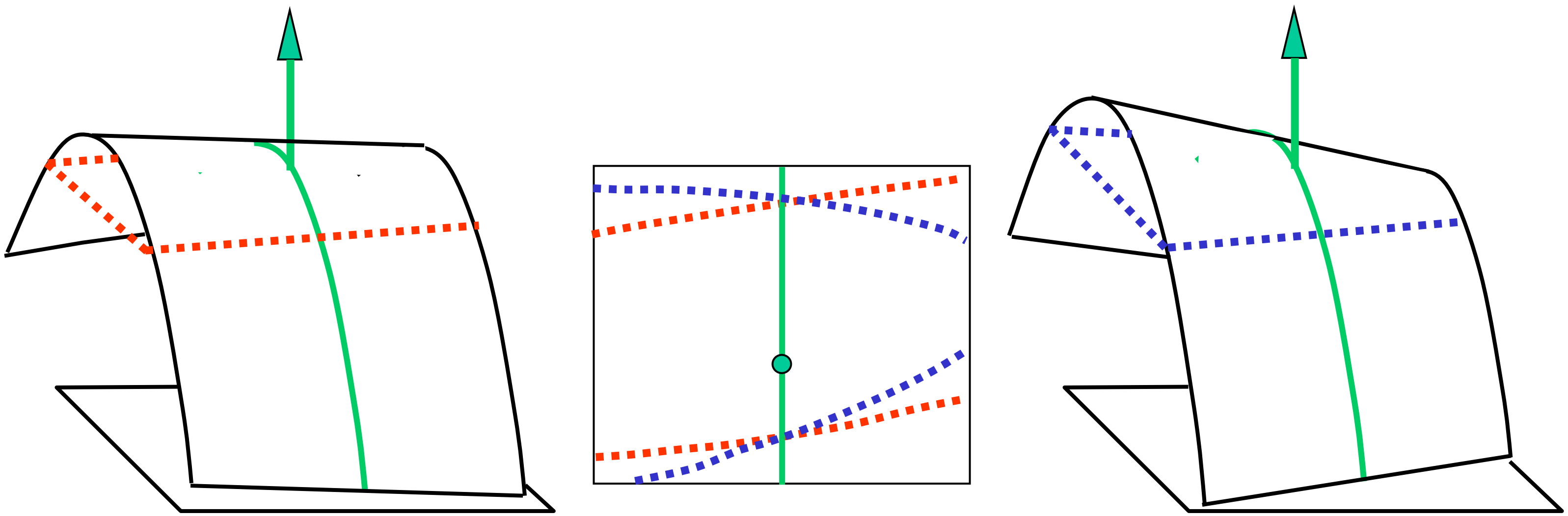


Example of Conical Anticline



Note on the Schmidt Net how the fit by a small circle is better than the fit by a great circle

Conicity is an important parameter…..

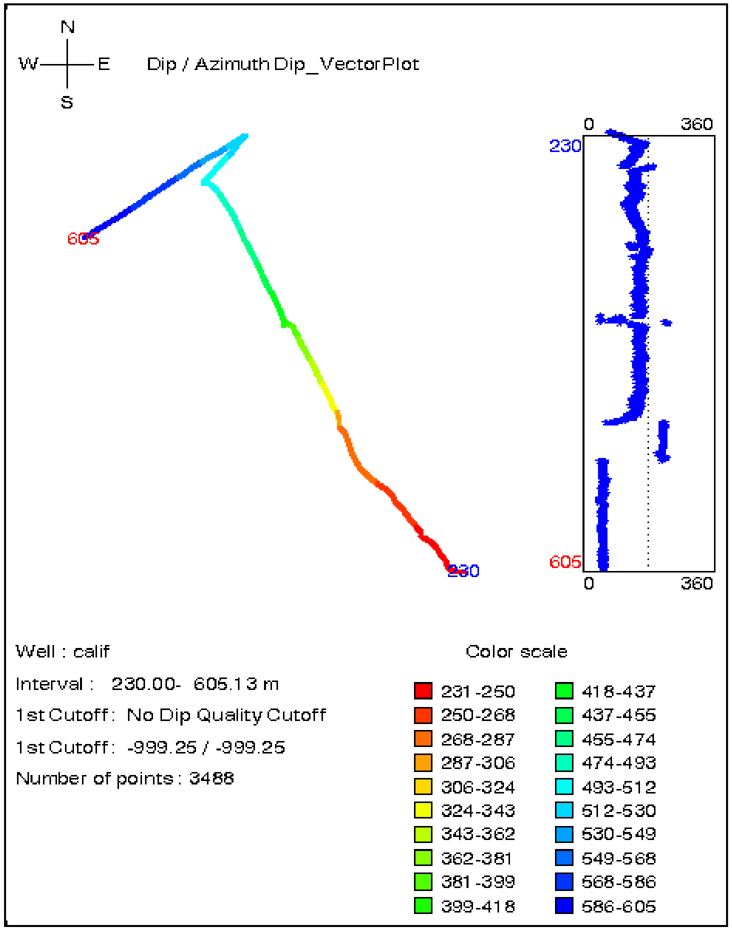


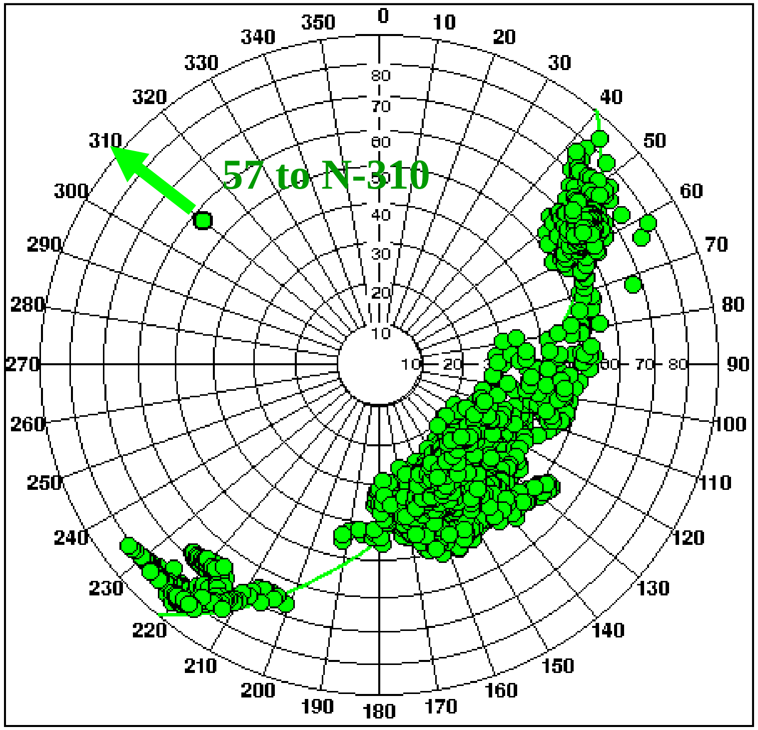
A B C

OWContact assuming:
cylindrical fold (left) or Conical fold (right)

Example of combining multiple rotations - 1

At bottom of a well, a fold has an axis (57 to N-310) tilted by 33 degrees.

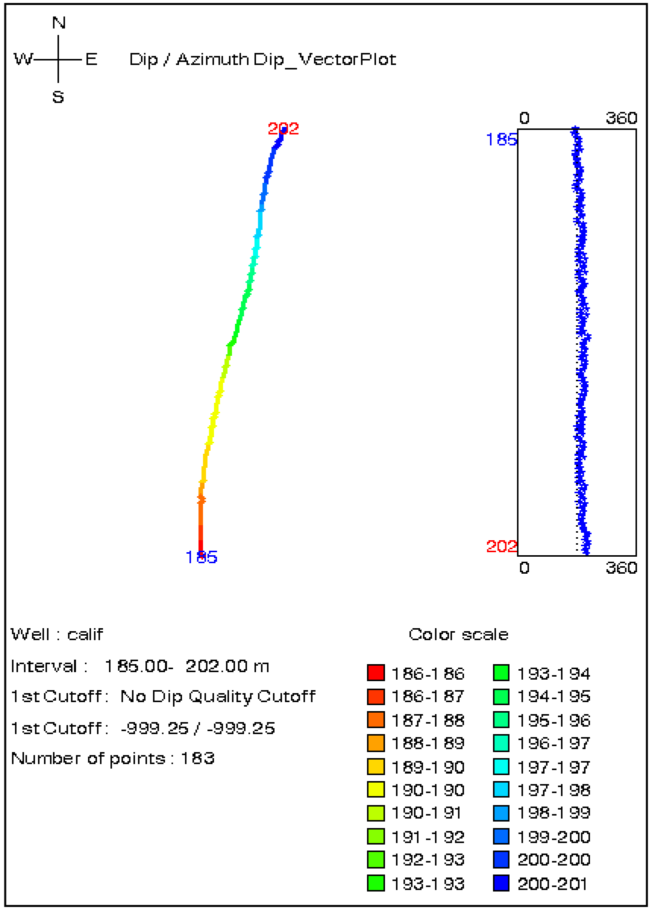


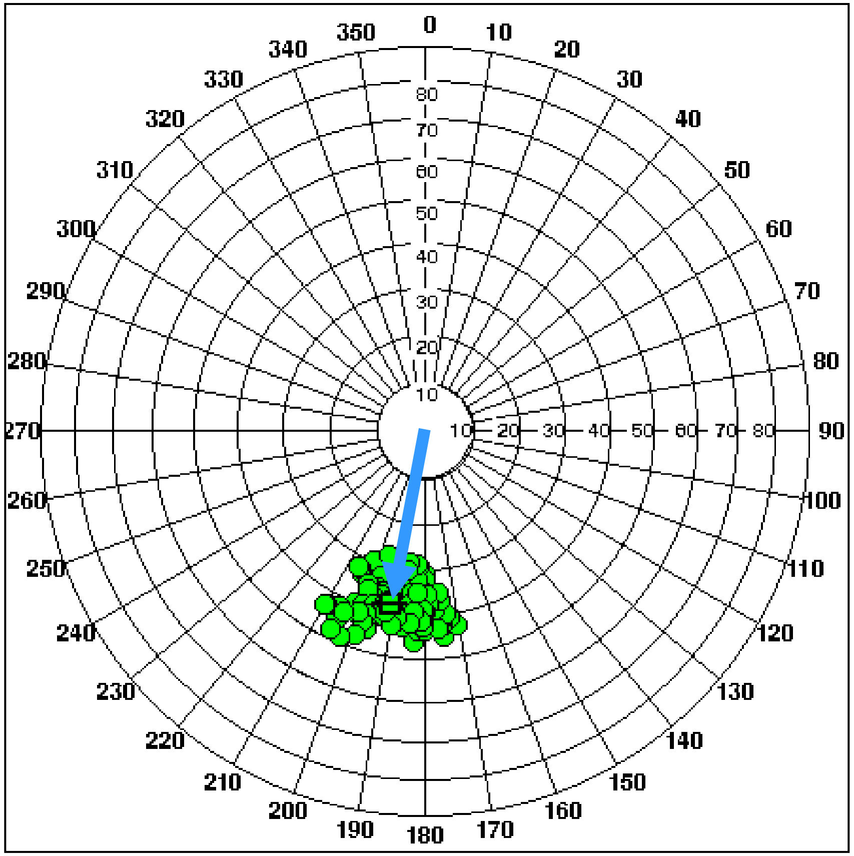


Example of combining multiple rotations - 2

At top of the same well, exists a main unconformity whose average structural dip is 37 deg to N-190.

There are obviously different folding and tilting phases!

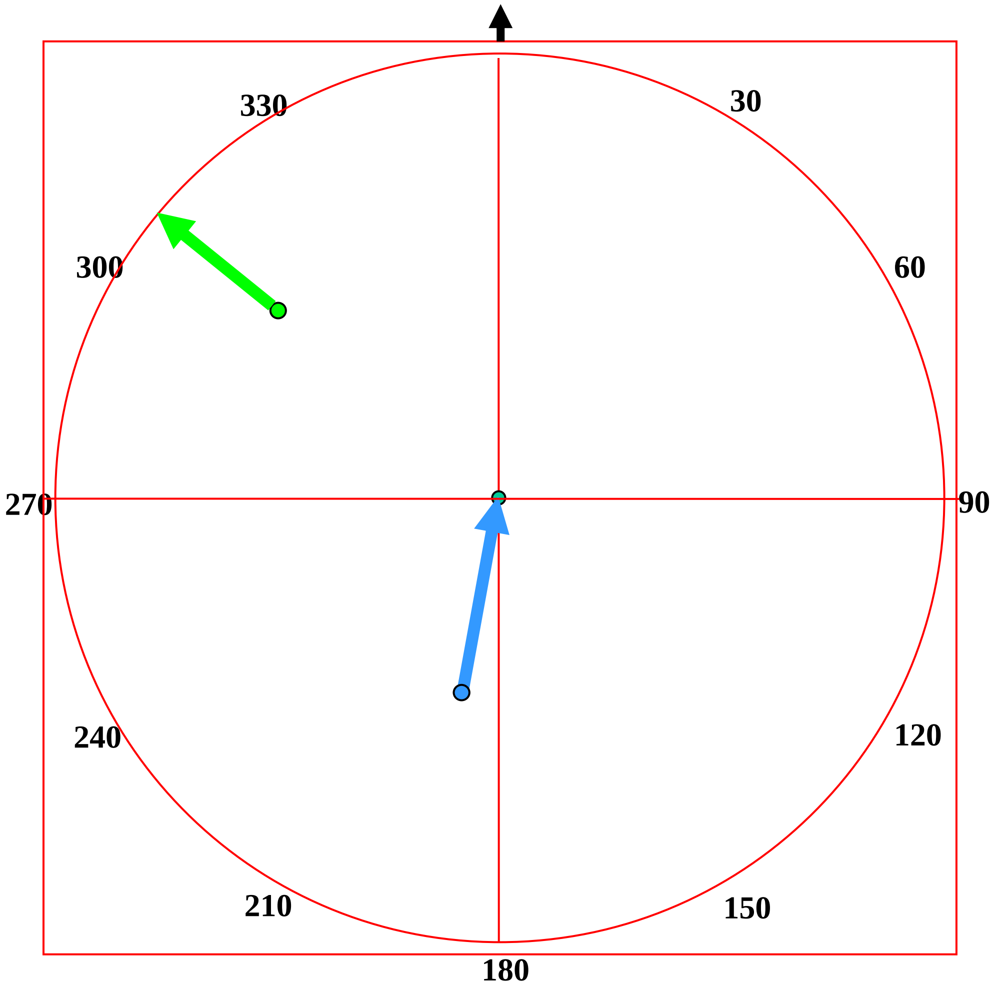




Example of combining multiple rotations - 3

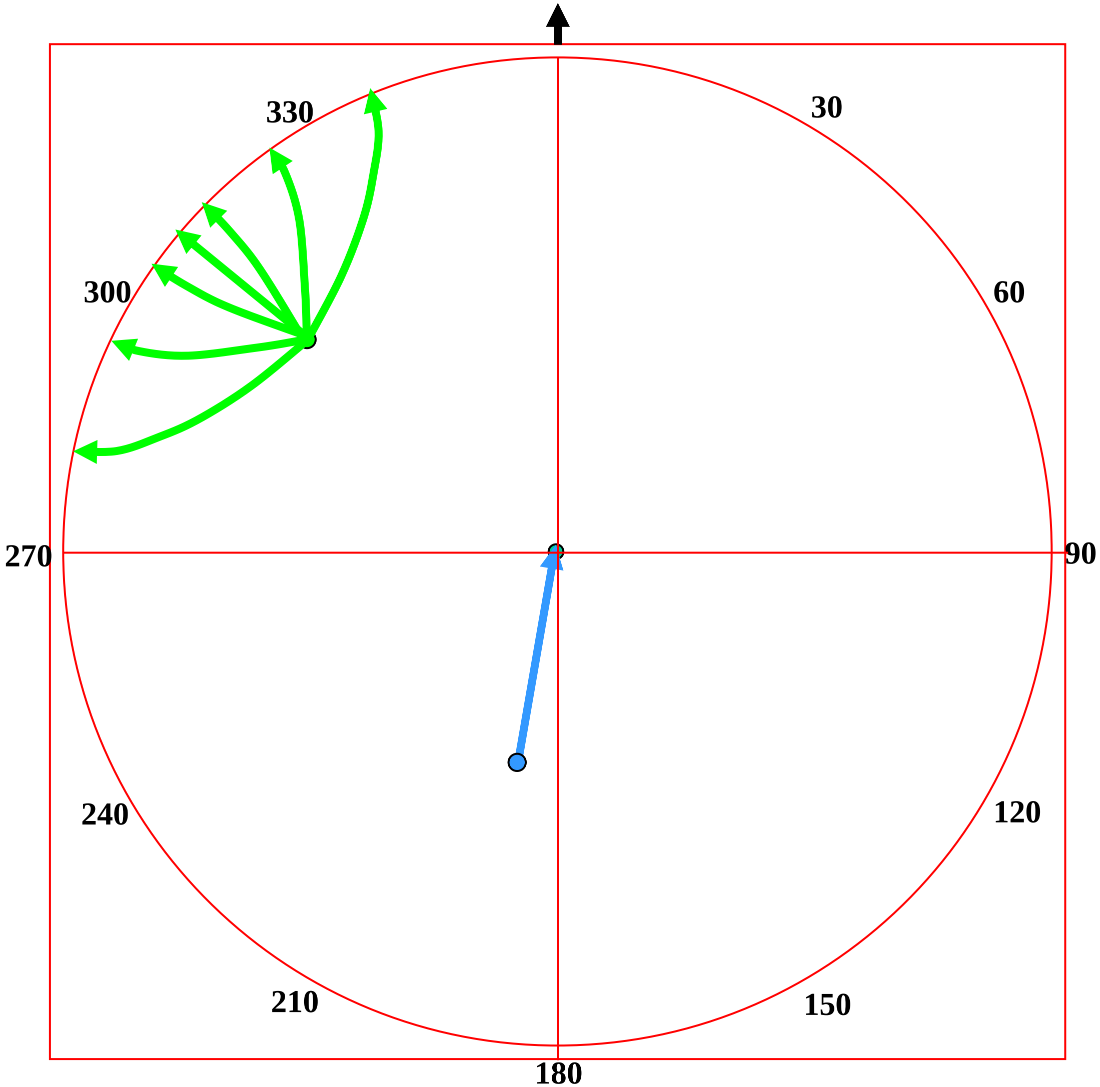
After removals, both the fold axis and the unconformity plane must be horizontal.

Question: Is the tilt of the fold axis compatible with the tilt of the upper unconformity?



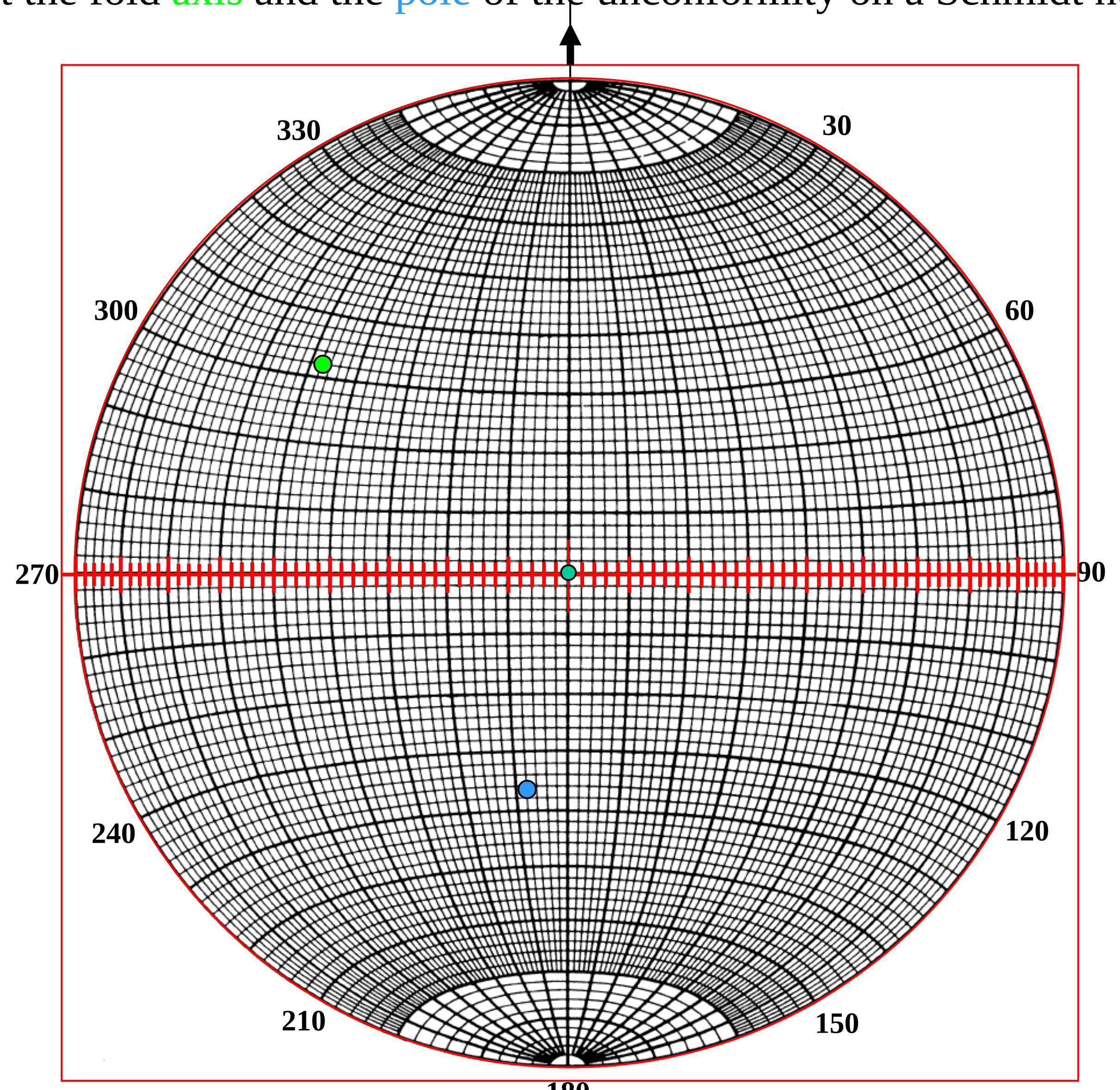
Example of combining multiple rotations - 4

While there is just a single way to remove structural dip above the unconformity, there are multiple ways to remove the fold axis



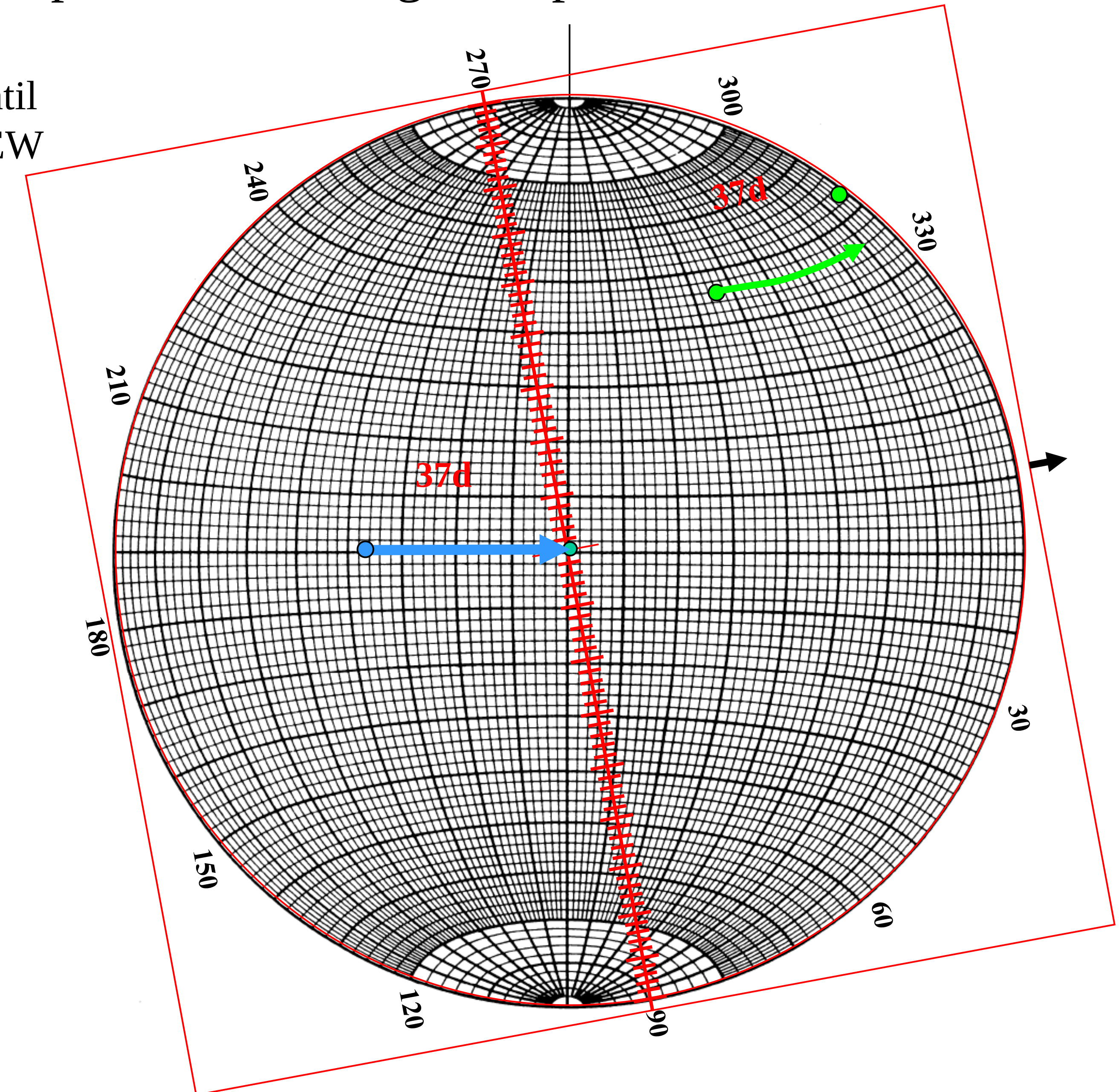
Example of combining multiple rotations - 5

Plot the fold axis and the pole of the unconformity on a Schmidt net

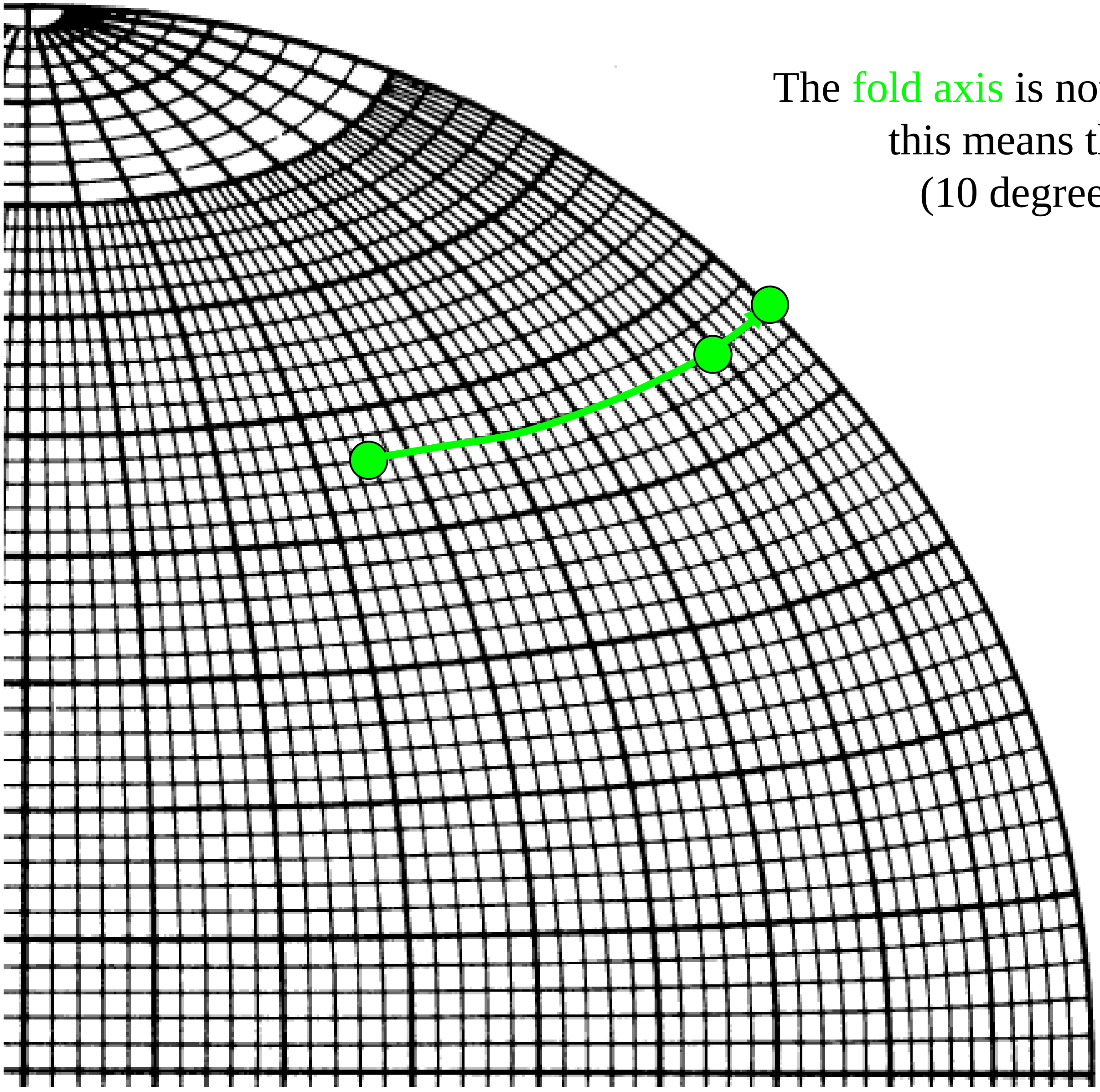


Example of combining multiple rotations - 6

Rotate the transparent until the pole appears on the EW axis of the net.
Then rotate the fold axis by the same angle on the small circle



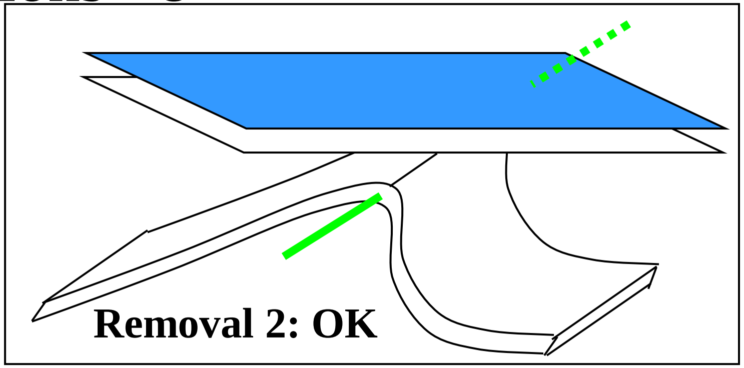
Example of combining multiple rotations - 7

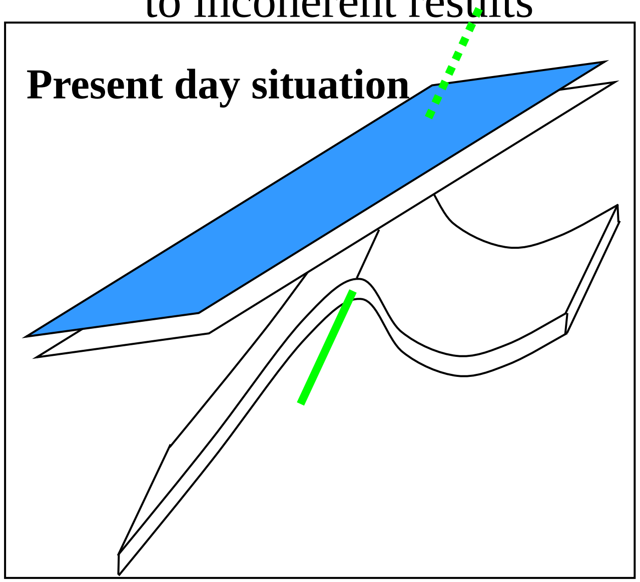


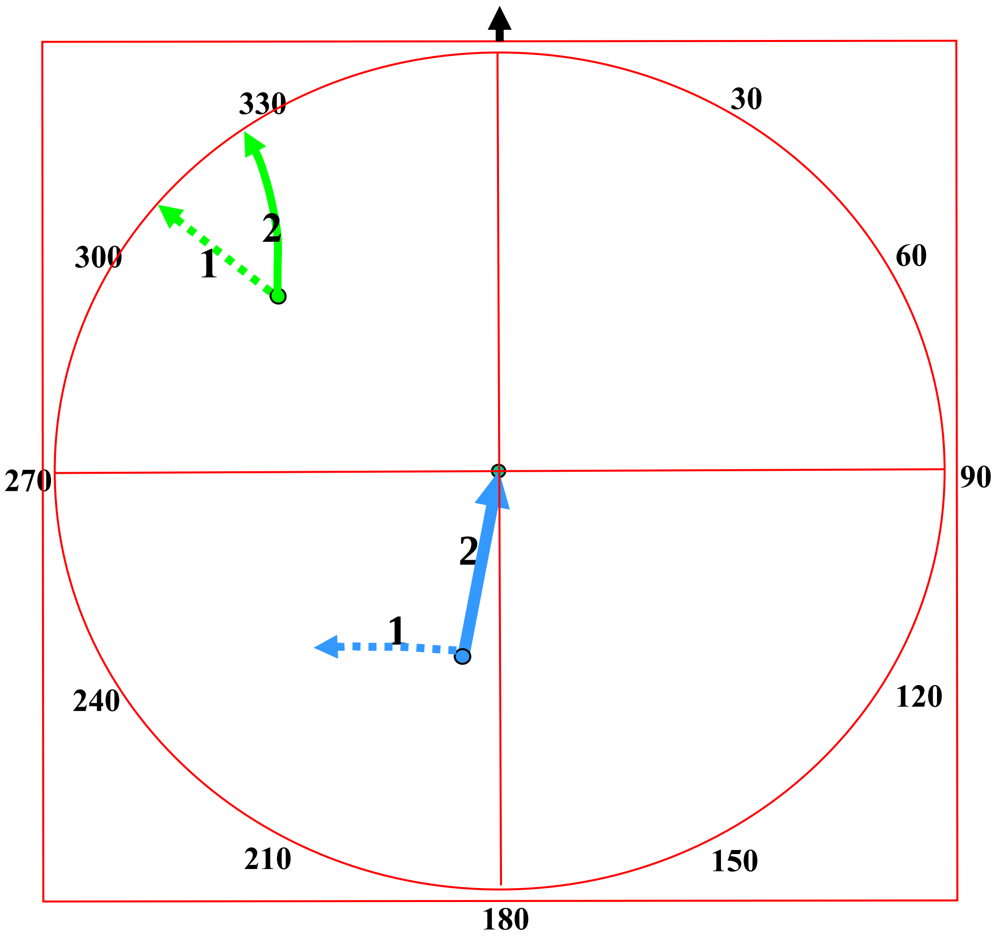
The fold axis is not perfectly removed; this means that tilting has begun (10 degrees) before deposition of the upper layers

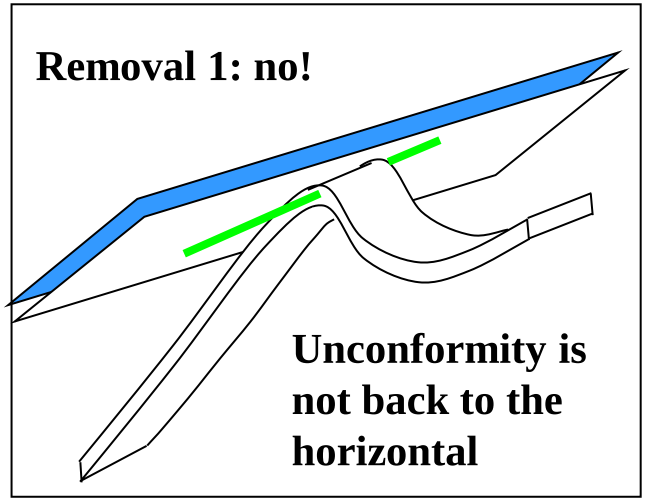
Example of combining multiple rotations - 8

In this particular example, a direct removal (1) of the fold axis, not accounting for the removal of the unconformity would have lead to incoherent results

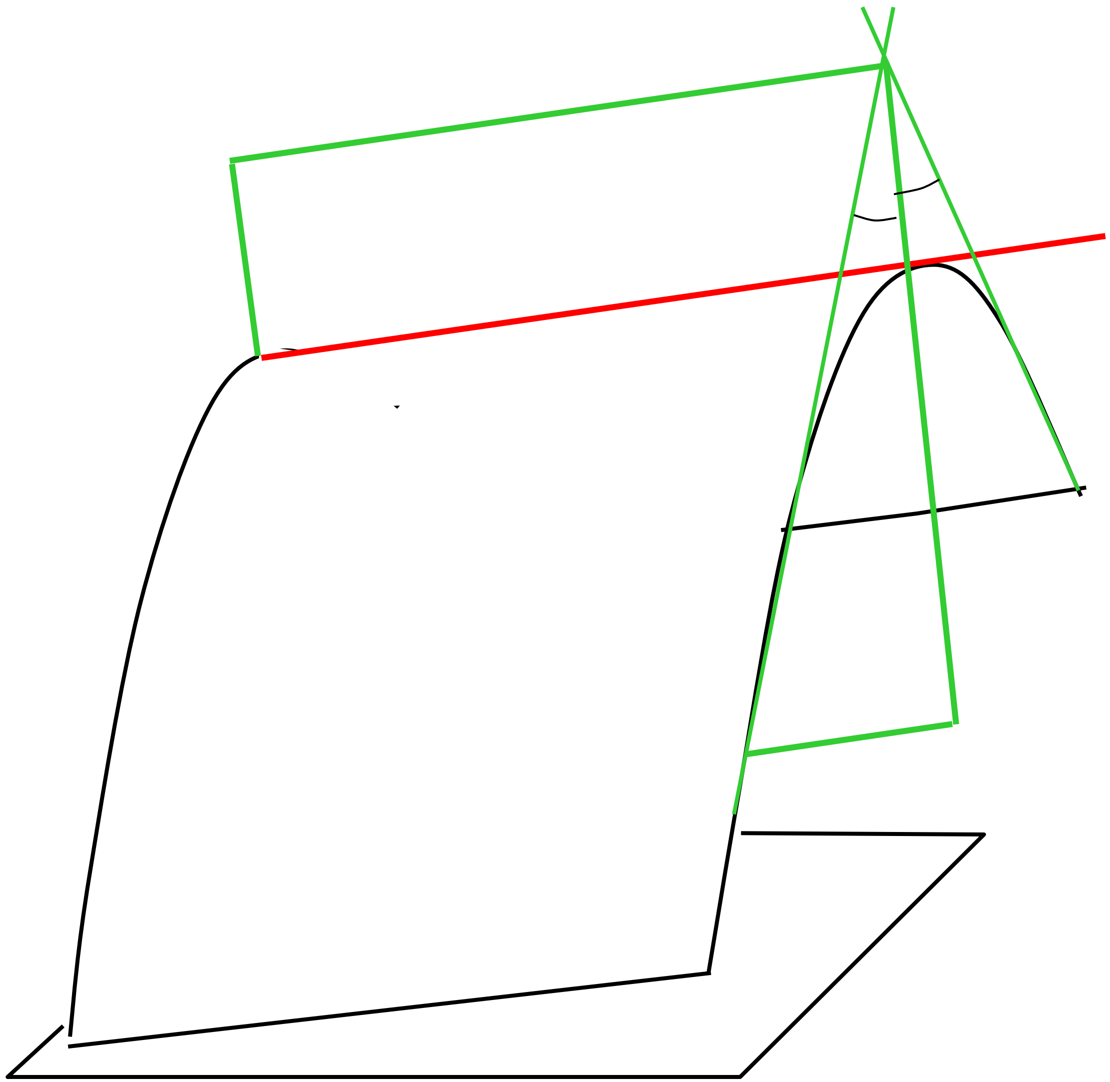








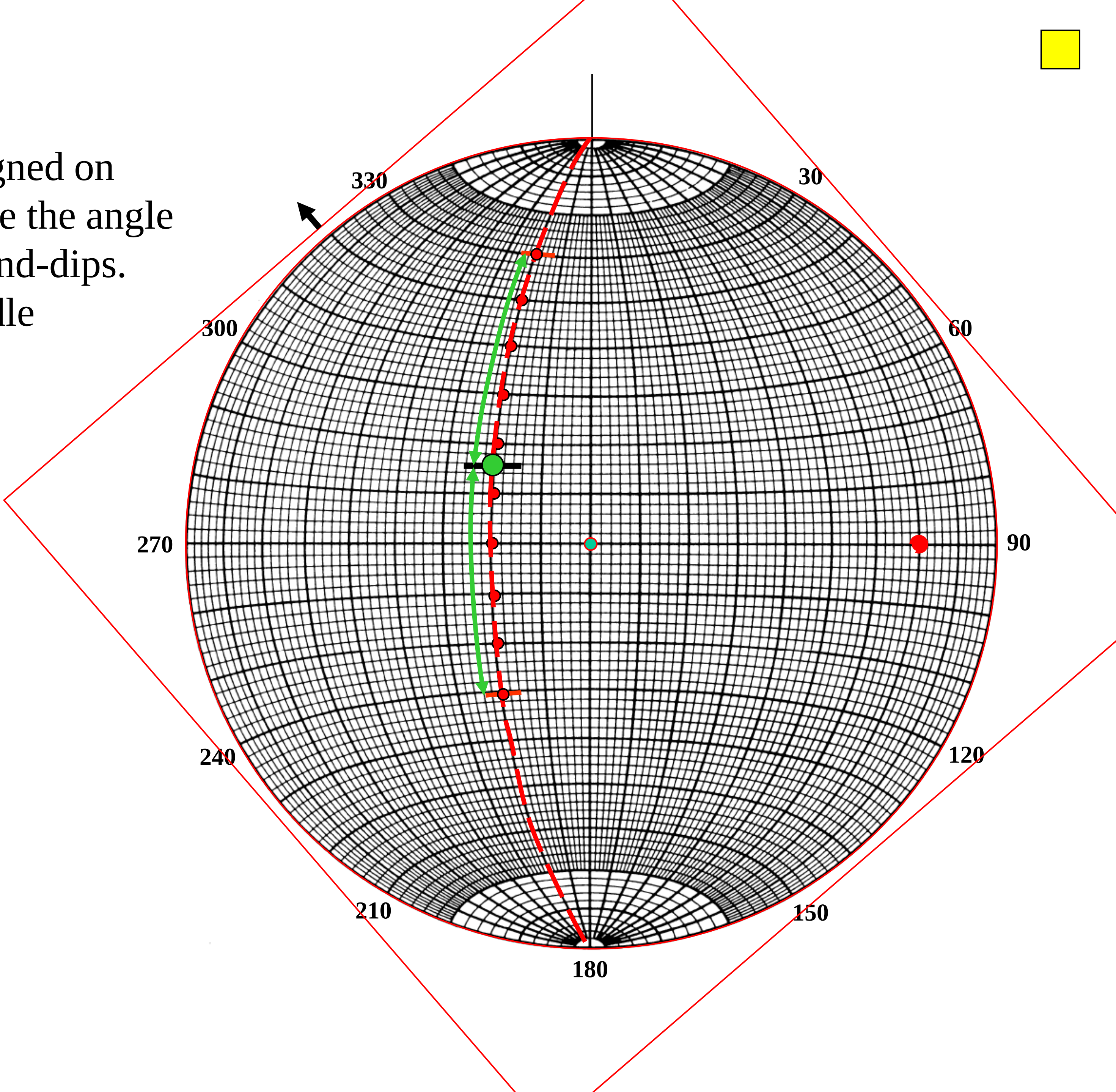
Axial plan determination



An axial plane:
contains the fold axis
and
is the bisector of the
Two limbs

Axial plane - 1

When dips are aligned on GC or SC, measure the angle between the two end-dips. and mark the middle point

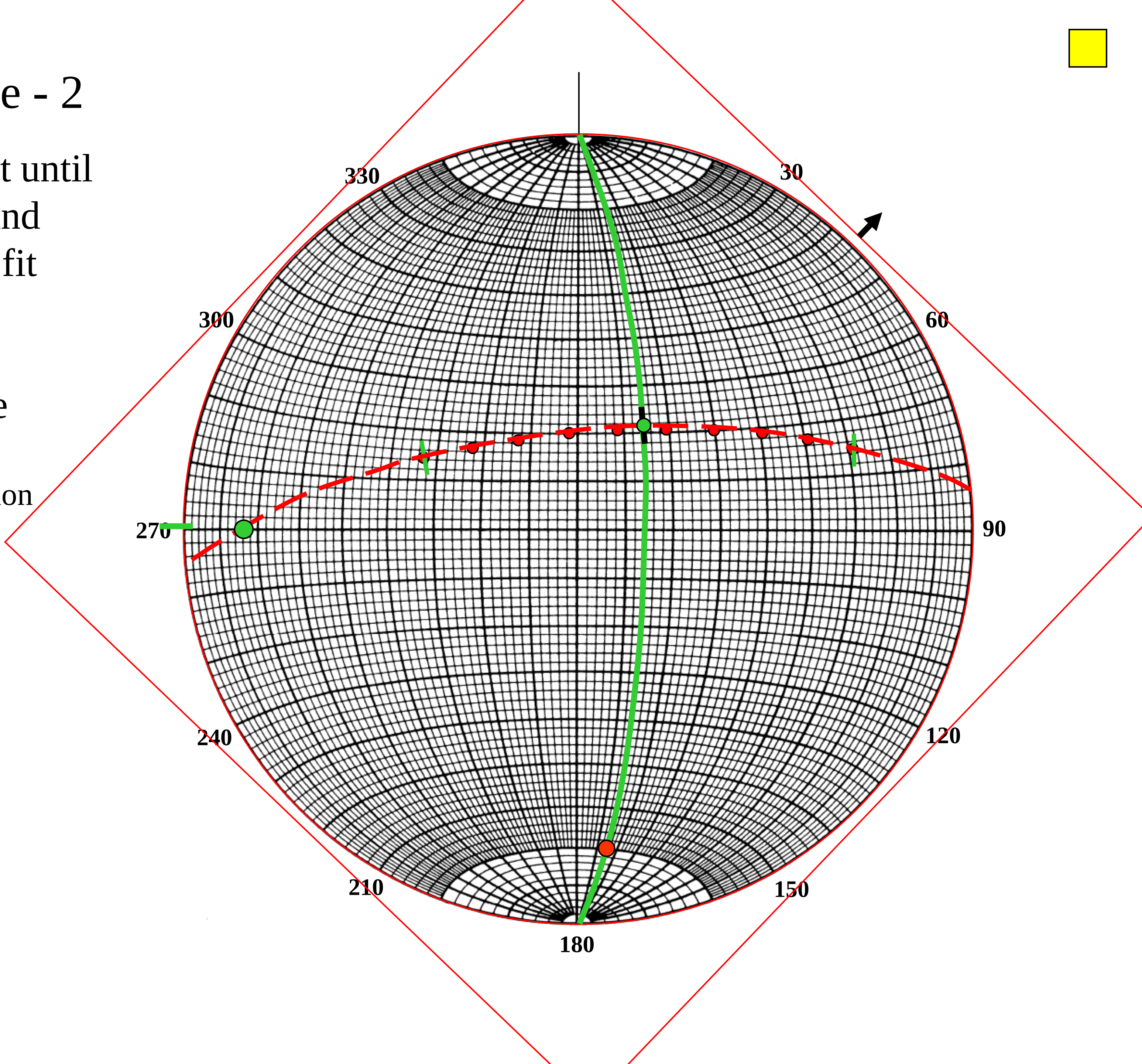


Axial plane - 2

Rotate the plot until the fold axis and the mid-point fit the same GC

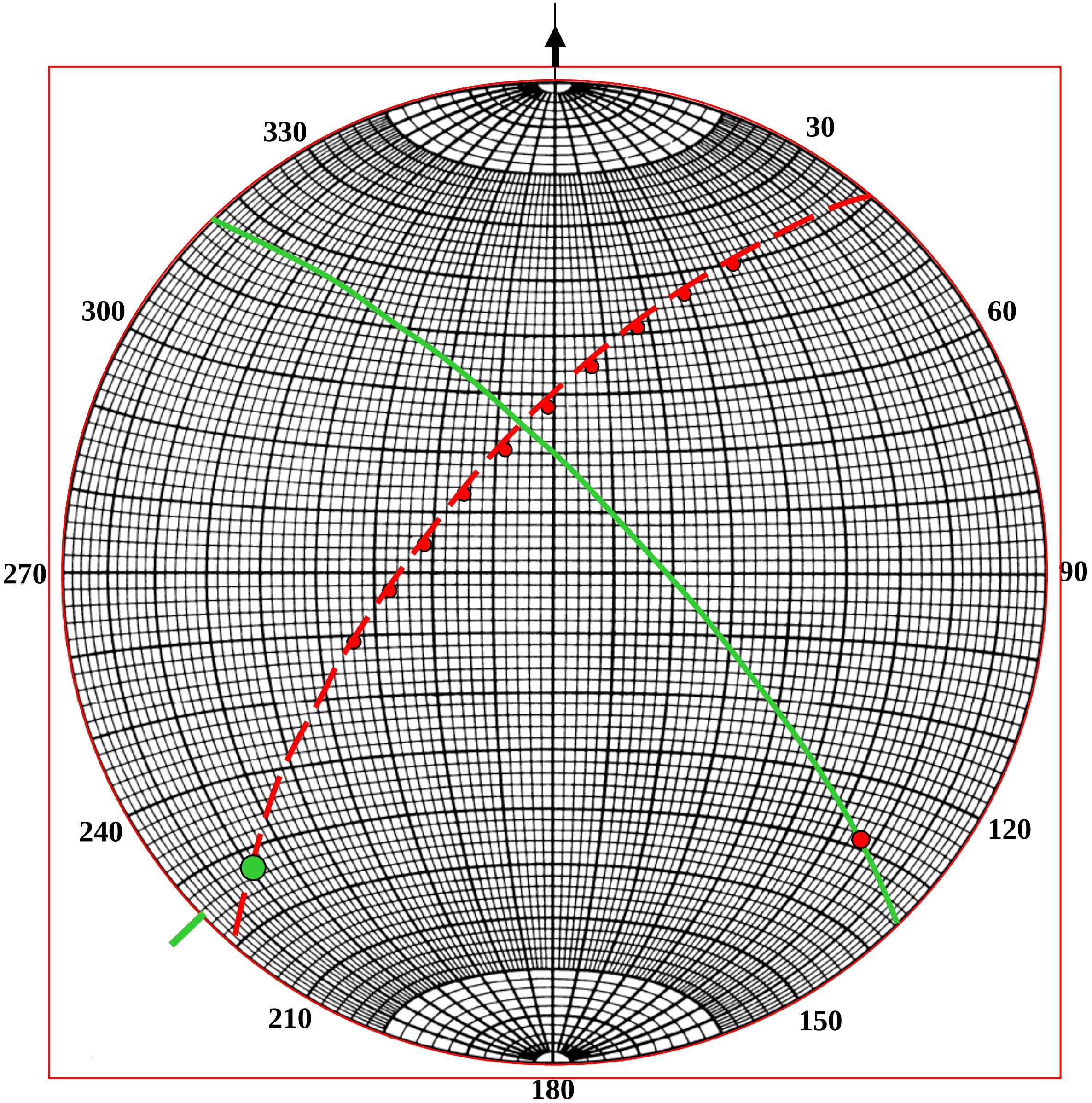
This GC is the Axial Plane
(used for translation In StrucView)

It dips 76 deg

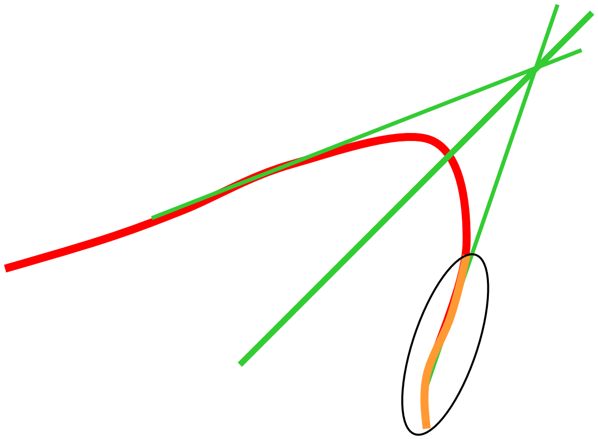


Axial plane - 3

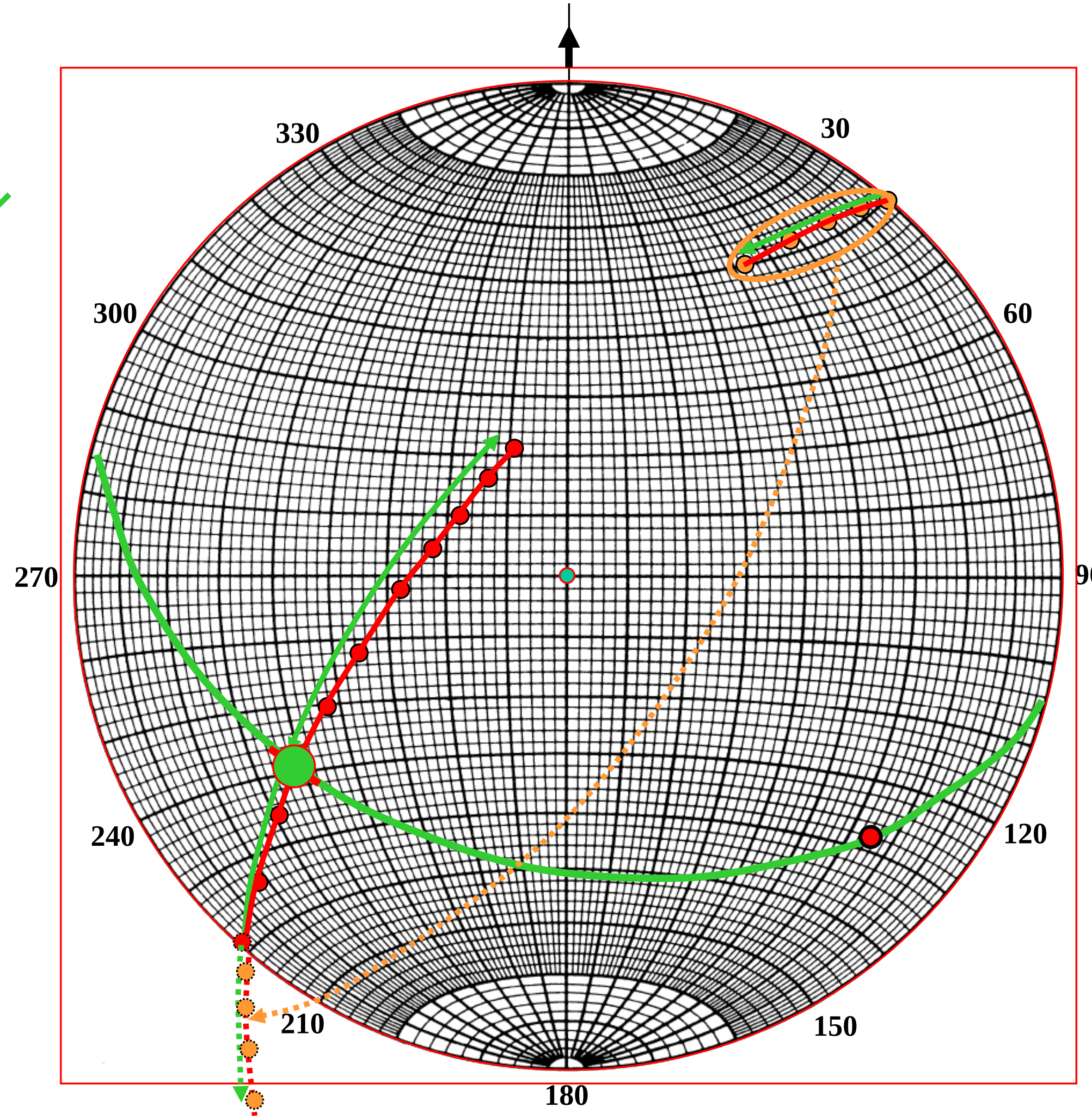
Back to the initial position gives the azimuth of the axial Plane (N-226)



Axial plane - 4

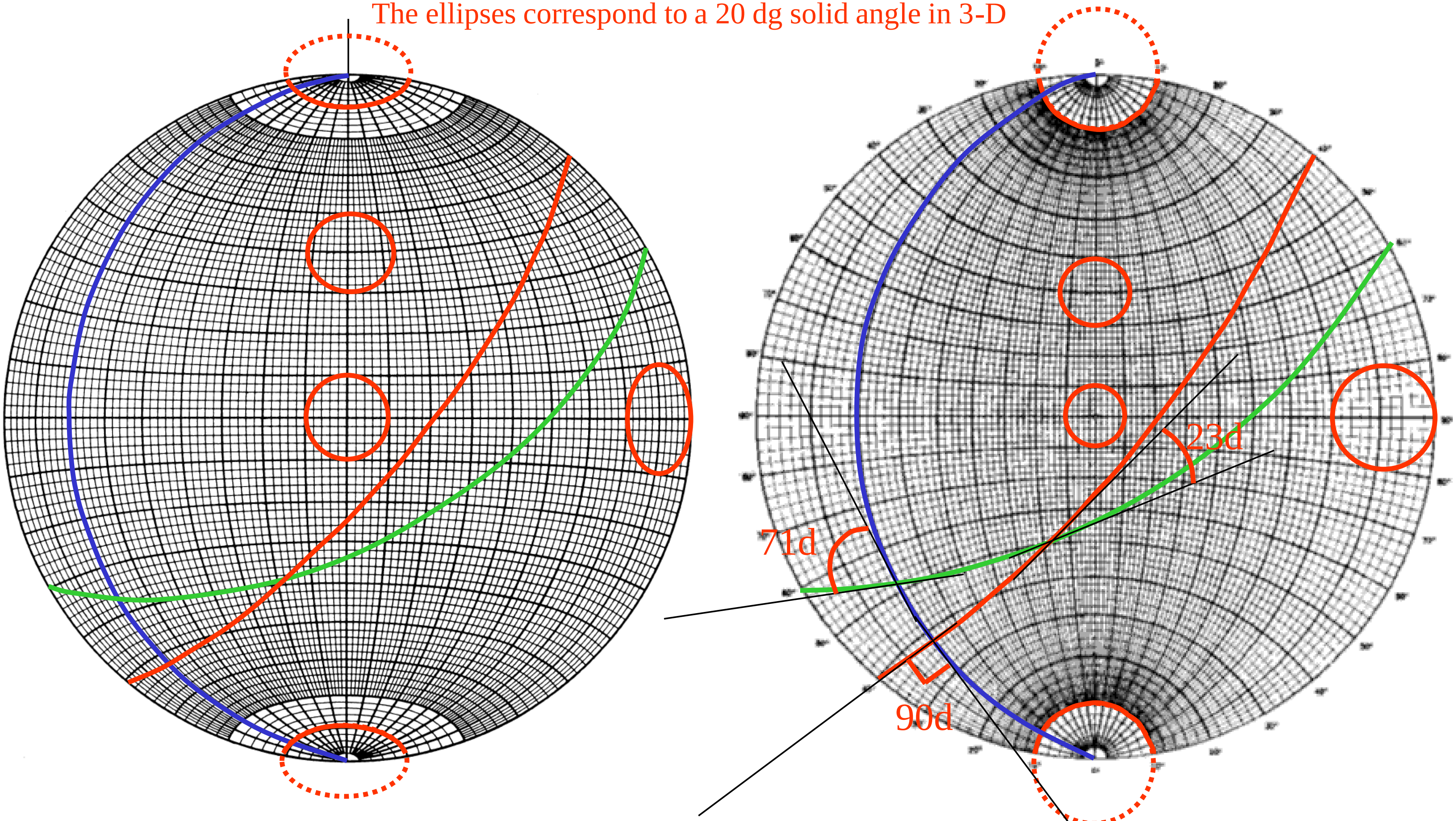


When one of the limbs
Is overturned, the
mid-point is defined
as shown on the figure



Schmidt Net | Wulff Net

The ellipses correspond to a 20 dg solid angle in 3-D



The different ellipses are equal in surface, it means that density on the net reflects correctly density on the sphere.

The ellipses are very different in surface, it means that a Wulff net does not reflect the actual density.
The angle at the intersection between two GC corresponds to the true angle between the planes in 3-D; but who uses a protractor on a screen? Moreover this angle is easily obtained from poles as explained previously.