Lab 3: Stereonets

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1 Introduction

In structural geology it is important to determine the orientations of planes and lines and their intersections. Working out these relationships as we have in Cartesian x-y-z coordinates, however, is a cumbersome and tedious task. The easiest way to handle orientation problems of lines and planes is through the use of stereographic projections. The use of stereographic projection – or stereonets – is the bread and butter of structural analysis. They are used to work out many tricky three dimensional relationships; they are used to plot and represent all kinds of geometric data that you collect in the field; they are used in the analysis of that data. From now, until the end of the semestre, hardly a lab will go by that won't use these. The purpose of this lab is to make you all masters of the stereographic projection. We will develop these techniques using paper, pencil and a stereonet, but will introduce software programmes that plot data stereographically.

In stereographic projection, planes and lines are drawn as they would appear if they intersected the bottom of a transparent sphere viewed from above[1]. To do this on a flat sheet of paper we use a two dimensional projection of the sphere called a stereonet. The stereonet shows the projection of a set of great circles and a set of small circles that are perpendicular to one another (just like longitude and latitude lines, respectively, on the globe). These form a grid that we can use to locate the position of variously oriented planes and lines.

Great circle: A circle on the surface of a sphere made by the intersection with the sphere of a plane that passes through the center of the sphere. The longitude lines on a globe are great circles.

Small circle: A circle on the surface of a sphere made by the intersections of a plane that does not pass through the center of the sphere. The latitude lines on a globe are small circles. Note also that the latitude and longitude lines on a globe are perpendicular to each other.

A stereonet should be visualized as the bottom half of a sphere. Planes intersect the sphere as great circles and lines intersect the sphere as points. Its helpful when starting out with stereonets to visualize the plane or line as it cuts through a 3-dimensional bowl (props may be helpful).

1.1 Basic techniques

Plotting a plane: Example: plot a plane with attitude 060/20. 1. On tracing paper mark a north arrow through the north pole of the net. 2. To locate the line of strike, count 60ř east of north on the outer circle. Mark this point on the outside circle of the net, and on the opposite side (180ř away). 3. Rotate the tracing paper until the strike line intersects the north pole of the net. This positions the tracing paper so that dip may be plotted using the great circle grid as a reference. 4. To plot dip, count off 20ř inward from the right hand side of the outer circle along the EW diameter of the net (always the right hand side if using the right hand rule, otherwise decide which direction to count in from based on the direction of dip). Trace, from pole to pole, the great circle arc that intersects this point. 5. Rotate back to the starting position and check that your plotted plane makes sense. Visualize!

Plotting a line: Example: plot a line with attitude 40/025[2]. 1. On tracing paper mark the north arrow. 2. Locate the direction of bearing by counting off 25ř west of north on the outer circle. Mark this point. 3. Rotate the bearing mark to coincide with the nearest great circle diameter of the net (the N, S, E or W poles) and count inward 40ř from the outer circle. 4. Rotate back to check if your plotted line makes sense.

[1] Note that using the bottom hemisphere of this sphere is just a convention. Mineralogists use the top hemisphere, but they are a weird lot, to be sure

[2] Note the convention we use: trend and plunge data are plotted as plunge and trend. The azimuthal measurement – strike or trend – is always written down as three digits, and the inclination measurement is always two measurements. This prevents a great deal of confusion

Figure 1:

Pole to a plane: Planes are awkward to deal with, but any plane can be represented more simply as a line that intersects it at a right angle. Example: plot the pole to a plane with attitude N74E, 80N 1. On tracing paper, mark the north arrow. 2. Mark the strike N74E on the stereonet and rotate it to north as if plotting the plane. 3. Count 80 in from the edge as you would for finding the dip of the plane. Now count an additional 90ř. Alternatively, count 80 from the center of the stereonet rather than the outer edge. Mark this point, its is the pole to the plane. 4. Check to make sure your pole makes sense.

Line of intersection of two planes: 1. Draw the great circle for each plane. 2. Rotate the tracing paper so that the point of intersection lies on the N-S or E-W line of the net. Mark the outer circle at the closest end of the N-S or E-W line. 3. Before rotating the paper back, count the number of degrees on the N-S or E-W line from the outer edge to the point of intersection. This is the plunge. 4. Rotate back. Find the bearing of the mark made on the outer edge of the circle. This is the trend.

Angles within planes: Angles within planes are measured along the great circle of the plane. The most common need is to plot the pitch or rake of a line within a plane. Example: a fault surface of N52W/20NE contains a slickenside lineation with a pitch of 43ř to the east (Figure 1a). Figure 1b shows the lineation plotted on the stereonet.

True dip from strike and apparent dip: 1. Draw a line representing the strike line of the plane. This will be a straight line across the center of the stereonet intersecting the outer circle at the strike bearing. 2. Plot the apparent dip as a pole. 3. We now have two points on the outer circle (the two ends of the strike line) and one point within (the apparent dip point), all three of which must lie on the same plane. Turn the strike line to lie on the NS line of the net and draw the great circle that passes through these points. 4. Measure true dip of plane along EW line of net.

Strike and dip from two apparent dips: 1. Plot both points representing the apparent dips lines. 2. Rotate the tracing paper until both points lie on the same great circle. This plane is the true strike and dip of the bed.

Vertical axis rotations: 1. Rotations about a vertical axis affect only the strike of the plane, while dip remains unchanged. Rotations are measured along the outer circle.

Example: What is the new attitude of a plane oriented N60W/45NE after a rotation of 30ř clockwise about R (vertical axis)?

Answer: N30W/45NE

Rotations about a horizontal axis parallel to the strike Rotation about the strike line affecst only the dip of the plane while the strike remains unchanged. In this case the overlay is rotated such that the strike of the plane (which is the rotation axis) coincides with the NS line, and the rotation is measured along the great circle grid.

Example: What is the attitude of a plane oriented N20E/80SE after a rotation of 50ř counterclockwise about R? Answer: N20E/30SE

Note that during rotation all points on the original great circle projection of the plane move along small circles to points on the rotated arc of the plane. In this way, arc lengths of the initial projection of the plane are preserved during rotation. The rake of a linear element in the plane is thus constant regardless of the orientation of the plane.

General rotations Rotations about any other axis (the usual case in geology) are trickier and are most easily done with poles to the planes rather than the planes themselves. We simplify the problem by first rotating the rotation axis to be horizontal, performing the required rotation, and finally returning the rotation axis to its original orientation.

Example: Find the new attitude of a plane oriented N30E/30SE after a rotation of 60ř counterclockwise about a rotation axis (R) EW/30E 1. Plot R, plane and pole to plane (Figure 4a) 2. Rotate R to horizontal position (R'). To maintain constant angular relationship between P and R, P must be rotated by the same amount along small circle. (Figure 4b) 3. Position R' parallel to the NS axis of the net and perform 60ř counterclockwise rotation by moving P' to P" (60ř measured on small circle). (Figure 4c) 4. Restore R' to true orientation. Simultaneous rotation of P" gives true attitude of pole to rotated plane (P"'). Plane itself is then reconstructed from the pole. (Figure 4d)

Cones: Because a drill core rotates as it is extracted, the orientation of a bedding plane cannot be determined, but a range of possible orientations can be defined. Lines perpendicular to the sides of the cone, representing poles to bedding, pass through the center of the sphere and intersect the lower hemisphere as two half-circles or one circle. 1. Plot the borehole. 2. Rotate the tracing paper so that the borehole lies along a great circle (I usually start with the straight line through the center and work out along each great circle in 10ř increments). Count out the number of degrees between the angle of the borehole and the angle of the bedding in both directions along the great circle line and make a mark. Do the same for each great circle line that you can rotate the borehole point to. 3. These marks should define a circle or two curved lines. You get a circle when the entire cone intersects the lower hemisphere (usually for a small angle between the borehole and the bedding or for a steeply dipping borehole). Two lines result when portions of the lower and upper cone both intersect the lower hemisphere of the stereonet (for a large angle between the borehole and bedding or a shallowly dipping borehole). A horizontal borehole always results in two symmetric lines.

More on Rotations When finding the original orientation of features that have been tilted, rotate the tilted plane back to horizontal using its strike line as the rotation axis. Remember to rotate everything else on the plot by the same number of degrees along the small circles perpendicular to the rotation axis.

-To rotate the limbs of plunging folds back to horizontal, first rotate the fold axis back to horizontal (rotate this about a horizontal axis perpendicular to the trend of the fold axis). Now rotate the fold limbs back to horizontal using the (now horizontal) fold axis as the rotation axis.

-Always keep in mind that the true tilting could be much more complex that what we assume in our simple stereonet manipulations.

-Keep the following in mind when rotating objects in a stereonet. Planes, lines and cones all pass through the origin and have a corresponding upper portion that we do not see. They sometimes, however, come into play when we do rotations or plot cones. For example, imagine a line trending N and plunging 45 degrees. It would plot as a point halfway between the edge and the center of the circle on the north south line. If we rotate the line around a horizontal, north striking axis, the pole traces a path towards the edge of the stereonet along a small circle line. When rotated 90ř the pole plots directly on the edge of the stereonet. The other end of the line also plots as a pole 180ř around the edge of the stereonet, and these two points are essentially the same thing and define the same line. Continuing the rotation, the pole in the northern half of the stereonet disappears (intersects the upper rather than lower hemisphere) and the pole now follows a small circle line in the southern half of the stereonet.

2 Resources

Stereographic plotting software is easily found on the Internets. Check out Rick Allmendinger's Stereonet (Mac and Windows) programme at:

http://www.geo.cornell.edu/geology/faculty/RWA/maintext.html

Rod Holcombe's GEOrient is promising, as well (Windows):

http://www.holcombe.net.au/software/index.html

3 Exercises

For each problem you should turn in a separate piece of tracing paper on which you should label everything that you plot. Make sure you draw the primitive (the outline of the stereonet), and label the cardinal directions. Make sure you indicate your answer clearly and include any comments you feel are necessary for someone to figure out what you've done.

3.1 Basic operations

1. Plot and label the following planes as both traces (great circles) and poles (points). For quadrant or dip/dipdirection convention, convert to azimuth and right hand rule first.

   (a) N20W/40W

   (b) 065/90

   (c) N5E/10E

   (d) Dip 70 towards 030

   (e) Horizontal plane

2. Plot and label the following lines (trend and plunge):

   (a) 20/S45E

   (b) 00/322

   (c) 60/S85W

   (d) Vertical line

3. Plot the following planes and the lines within them. Figure out the trend and plunge of each line:

   (a) Plane strikes N30E, dips 45W; line pitches/rakes 30N (30ř down from N end of plane)

   (b) Plane is 075/20; line pitches/rakes 18°from E

   (c) Plane strikes N15W, dips 50W; line pitches/rakes 90W

4. Rotate the following lines 30°counterclockwise around a pole plunging 15°, trending 334. Figure out trend and plunge of each line after rotation:

   (a) 42 towards 312

   (b) Plunge 23, trend N20E

   (c) 42→210

5. Using either pencil and paper, or a downloaded stereonet programme, plot the measurements taken at Beavertail point. First, you will have to compile all the measurements from everyone. Carefully distinguish between bedding, cleavage and fold axes. Are there any relationships between the different kinds of measurements? I hope so.

3.2 Problem solving

1. a. Bedding in a sedimentary rock strikes N35W, dips 60SW. Plot this surface as a trace and a pole. b. plot the direction of grain elongation pitching 32NW in the bedding of (a). c. The hinge of a small fold plunges 46ř in the direction of N68E; plot this hinge line. d. Determine the attitude (strike and dip) of the plane containing the hinge and the grain elongation direction. Why is this plane interesting?

2. On a vertical exposure striking N75W (F1) the apparent dip of bedding (B) is 23W. On a second vertical exposure (F2) striking due north the apparent dip of B is 16S. What is the true strike and dip of B?

3. A vein (V) striking N18W and dipping 16SW intersects a fault (F) striking N70E and dipping 87S. What is the trend and plunge of the line of intersection of F and V.

4. The attitude of a bore-hole is trend S22E, plunge 40. On a core sample, the angle between the core axis and the pole of bedding is 60ř. Show all possible positions of the pole of bedding on the stereonet.

5. Two veins (V1 and V2) are found in a region where ore bodies lie along the intersection of the two vein systems. Past experience shows that the most information is obtained if a drill hole cuts the line of intersection of the two veins at 90ř and lies in the plane bisecting the veins acutely. What should the trend and plunge of the drill hole be if V1 strikes N62W and dips 64NE, and V2 strikes N34W and dips 70SW.

6. In a series of uniformly dipping sediments in which the bedding is generally obscure, a fault striking N15W and dipping 60SW produces no offset where it cuts a layer of conglomerate. Direction of movement on the fault is given by slickensides (elongated mineral fibers on the fault plane) trending N87W and plunging 59. From an aerial photograph, the general strike of the bedding is determined to be N45W. What is the dip of the bedding?

7. On one planar limb of a plunging fold the strike of bedding is N25E and the dip is 50NW; on the other limb the strike is N24W and the dip is 70NE. What is the trend and plunge of the fold axis? Is it an anticline or a syncline? Explain your reasoning.

8. The following data are from 3 non-parallel drill holes: Hole A: trend N42E, plunge 65; angle between core axis and bedding pole is 45ř Hole B: trend S60E, plunge 44; angle between core axis and bedding pole is 70ř Hole C: trend S5W, plunge 59; angle between core axis and bedding pole is 40ř Assuming that the bedding is uniform, find the attitude of the bedding.

9. Below an unconformity striking N37E and dipping 32NW a series of planar beds strikes N18W and dips 60W. What was the strike and dip of these beds at the time the unconformity was formed? What assumption do you have to make to arrive at an answer?

10. On one side of a fault, upright beds strike N43E and dip 75NW. On the other side of the fault, the beds are again upright and strike N74E and dip 54NW. From an air photo, the fault is seen to strike N20E. Assuming rotational movement on the fault, find: a. the dip of the fault b. the amount of rotational movement on the fault in terms of an angle between lines on opposite sides of the fault that were parallel before rotation. (Note that these lines must be perpendicular to the axis of rotation.)