

Structural Geology Lab Project

Title: **Borehole analysis using stereographic projection**

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Level: Intermediate or Advanced

Goals: To give students an open-ended and applied lab project that utilizes advanced methods in stereonet analysis. These methods are 1) plotting a small circle that represents the possible orientations of pole to bedding (in this case cross bedding) in an unoriented core; 2) to make stereonet rotations involved in forward modeling of fold limb rotation and fold plunge.

Preparation: I recommend lecture and/or reading preparation for stereonet methods in small circle plotting and small circle rotations.

Borehole analysis using stereographic projection

Two petroleum companies have adjacent land holdings in the Anschutz Ranch East field in Utah-Wyoming, a foreland fold-thrust belt petroleum province (this was a real-life problem). They have drilled a number of exploration holes to help determine the detailed geometry of a fold structure, and are trying to model the reservoir volume below their respective land holdings. In the final and critical hole, they lost the hole but recovered a section of core in the middle of a thick eolian cross-bedded sandstone unit (Nugget Formation). Unfortunately the core was unoriented.

Here's the problem: The core shows only cross bedding, not true bedding. However, we need to determine the orientation of the true bedding in the borehole. The bedding orientation will affect the geometry of the modeled fold structure and therefore the amount of fold closure (amount of reserves). Of course, one company would like to see a shallow dip, the other a steep dip (millions of dollars are at stake).

The following information and geological constraints are known:

- the borehole is on the eastern limb of the anticline
- deviation of the borehole (90°-borehole plunge) $10^{\circ} \ 230^{\circ}$
- “dip” of crossbeds in the core 30°
- fold plunge and trend $8^{\circ} \ 015^{\circ}$
- *depositional* attitude of foreset beds (regionally consistent) $22^{\circ} \ 230^{\circ}$

The strike and dip of the true bedding in the hole can be determined only by constraining or assuming what the orientation of the core is (about the borehole axis). Using this information and *making some reasonable assumptions*, use a stereonet to determine the true attitude of bedding in the borehole. Hint: the solution requires forward modeling of the eastern fold limb.

What other methods might be employed to reach the same conclusion?

Guided solution to Anschutz Ranch East problem:

The solution to this problem requires to advanced stereonet methods: plotting of small circles and rotations along small circles. I solved this problem by using a forward fold model. In this model the pole to cross bedding in the eastern limb of the fold is rotated from its regionally known pre-folding (i.e., depositional) position to a position where it must cross the small circle containing all possible poles to cross bedding in the unoriented core. The pole to true bedding is then rotated from its pre-folding position (i.e., vertical) by the same rotations made for the cross bedding.

Step 1: Plot the borehole axis and a small circle that represents all possible positions of pole to cross-beds in the unoriented core. (The small circle is plotted by rotating the borehole axis point to any great circle, measuring 30° in either direction, and marking two points; this procedure is repeated until enough points are available to connect with a hand-drawn small circle (not really a perfect circle)).

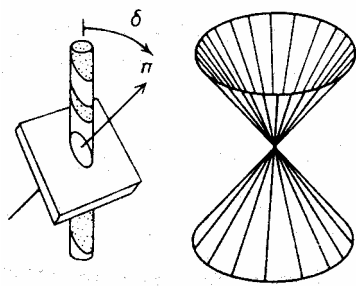


Diagram showing the angle δ (core axis \wedge pole to cross beds) which is the same as “dip” in the core. The right diagram shows the cone of all possible pole orientations in an unoriented core; this cone is represented on a stereonet by a small circle about the borehole axis.

Step 2: Plot the fold axis, and the point S_x = depositional position of pole to cross beds (regionally consistent). Plot the depositional position of the pole to beds (S_o = vertical).

Forward model the rotation of the eastern fold limb: rotate S_x along a small circle with the non-plunging fold axis as the rotation axis (0° 015°).

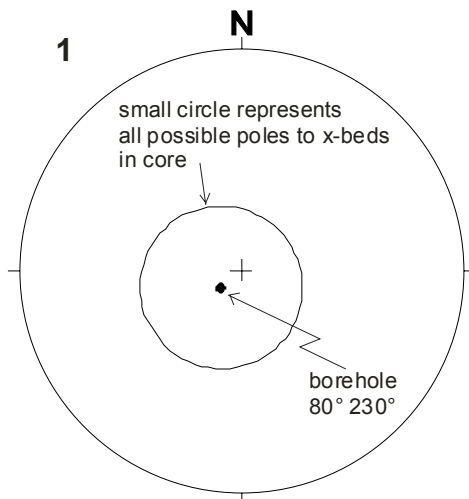
Forward model the fold plunge: rotate S_x along a small circle with 0° 105° as rotation axis, such that after 8° rotation (the fold plunge) the pole S_x falls on the small circle representing all possible poles to x-beds in the borehole. S_x will then have rotated 43° during the first rotation, then 8° during the second rotation.

Step 3: Rotate S_o the same rotations ($\sim 43^\circ$ then 8°) that were made in step 2. This then gives an answer of S_o (pole) = 46° 276° , or the S_o plane = 006° 46° .

Check answer: the poles to cross bedding (red triangle) and true bedding (red circle) should be 22° apart in the great circle that contains them. This confirms that the depositional dip of cross beds (22°) remained intact during the rotations.

Other methods that might be used to model the orientation of the core in the borehole (and the eastern fold limb):

- seismic (but expensive)
- other drill hole (also expensive)
- some method to orient the core - ?paleomag?



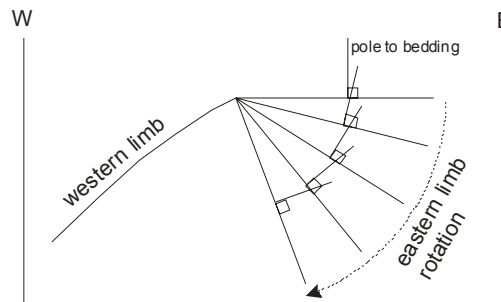
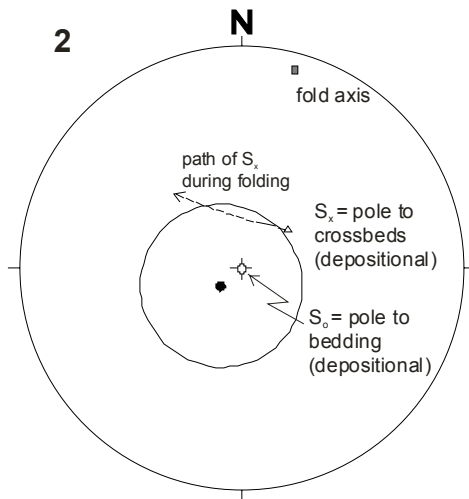
Guided solution to Anschutz Ranch East problem:

Step 1: plot borehole axis and small circle that represents all possible positions of pole to x-beds in the unoriented core.

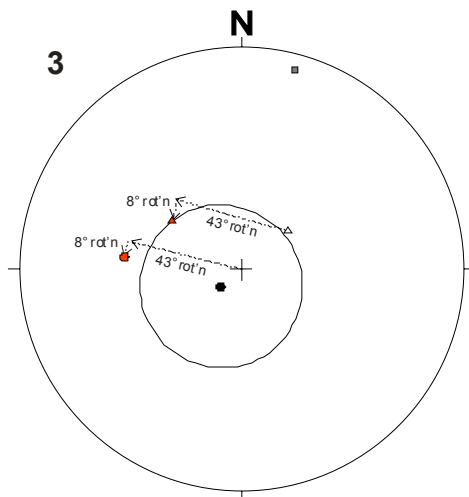
Step 2: plot fold axis, and S_x = depositional position of pole to cross beds (regionally consistent). Plot depositional position of pole to beds (S_o = vertical).

Model eastern fold limb rotation: rotate S_x along small circle with non-plunging fold axis as rotation axis (0° 015°).

Model fold plunge: rotate S_x along small circle with 0° 105° as rotation axis, such that after 8° rotation (fold plunge) the pole S_x falls on the small circle representing all possible poles to x-beds in the borehole. S_x will have rotated 43° then 8° .



Schematic cross section showing eastern limb rotation in forward model.



Step 3: Rotate S_o the same rotations ($\sim 43^\circ$ then 8°) that were made in step 2. This then gives an answer of S_o (pole) = 46° 276° , or the S_o plane = 006° 46° .

Check answer: the poles to cross bedding (red triangle) and true bedding (red circle) should be 22° apart in the great circle that contains them. This confirms that the depositional dip of cross beds (22°) remained intact during the rotations.