PS Modeling the Effect of Borehole Orientation on Stereonets*

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Abstract

It has long been known that borehole direction affects the number of fractures encountered in a well. In other words, if a well is drilled perpendicular to the dominant fracture direction, more fractures will be encountered than in a well parallel to the same fractures. However, when analyzing stereonets this is seldom taken into account, either qualitatively or quantitatively. Methods exist to model fracture distributions on stereonets. What has been missing is the ability to display the effect that borehole orientation has on them. Equations derived for calculating fracture density can be modified to estimate attenuation. Attenuation is modeled by first generating a unimodal or bimodal distribution of fractures and then culling those fractures based on the expected attenuation. The culling is done by randomly eliminating dips based on an attenuation value. For example, for an attenuation of 90%, only 10% of the fractures will be kept.

Modeling can demonstrate that two wells drilled through the same basic fracture set can have a very different appearance because of differing borehole deviations. The modeling has been especially useful in the study of joints, which are defined here as fractures that are roughly perpendicular to bedding dip and that end at bedding interfaces. (Joints are arguably the most common type of fracture in sedimentary rock.) A bimodal distribution is used to simulate a pattern of joints, because they tend to have a pattern in which the fractures form a girdle surrounding the great circle of the plane of dip. The angular scatter above and below the plane of dip was calculated using a normal distribution about the plane, while the broader angular scatter along the plane was centered on an arbitrary axis within the plane. The wells showing the greatest attenuation were where the borehole was roughly perpendicular to dip. This is actually quite common, because a vertical well in horizontal beds fits this description. In this type of well, attenuation can reduce the number of fractures by 80% or more. Horizontal wells are very different. This is immediately apparent when the fractures are widely distributed over a stereonet. At first glance, it will appear that there are two broad sets of fractures, but actually there is a band, perpendicular to the borehole direction, where the fractures have been sharply reduced.

Modeling the Effect of Borehole Orientation on Stereonets

Borehole direction affects the number of fractures encountered, the ***frequency***. As fractures approach parallel to the borehole, frequency is ***attenuated*** such that very few fractures are encountered. Modeling these effects can help in visualizing how polar plots are affected by borehole orientation.

Two polar plots (stereonets) have been developed to help analyze orientation effects on fracture frequency. The first, the ***shadow zone plot***, displays expected attenuation depending on the fracture angle to the borehole. The second, the ***predicted frequency plot***, displays expected frequency at all possible borehole orientations.

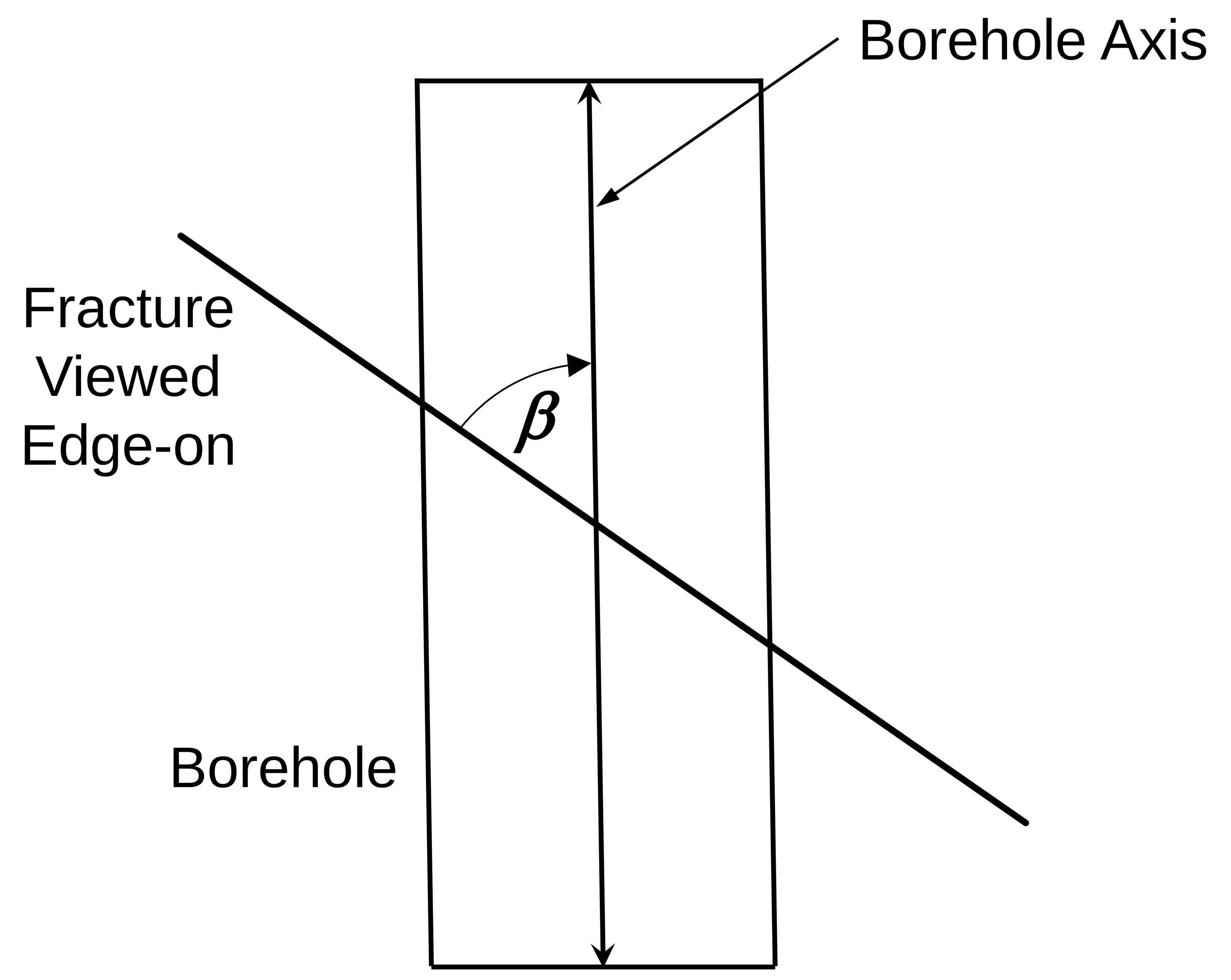
Frequency is the number of fracture intersections per unit length.

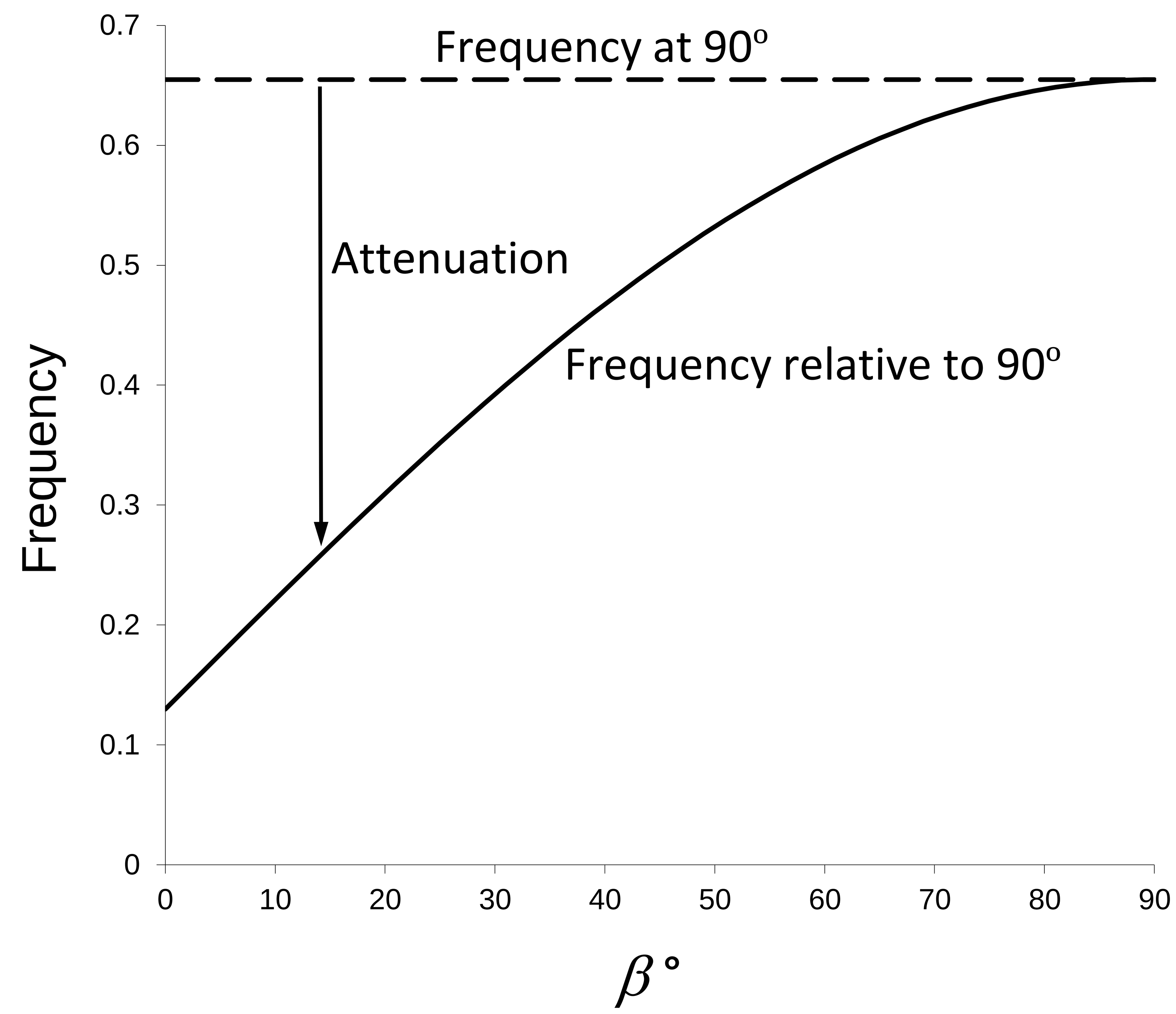
Attenuation is the decrease in frequency caused by fracture orientation relative to the borehole.

Predicted frequency is the frequency predicted for a given borehole trajectory relative to the observed frequency.

Apparent spacing, the inverse of frequency, is the average distance between fracture intersections.

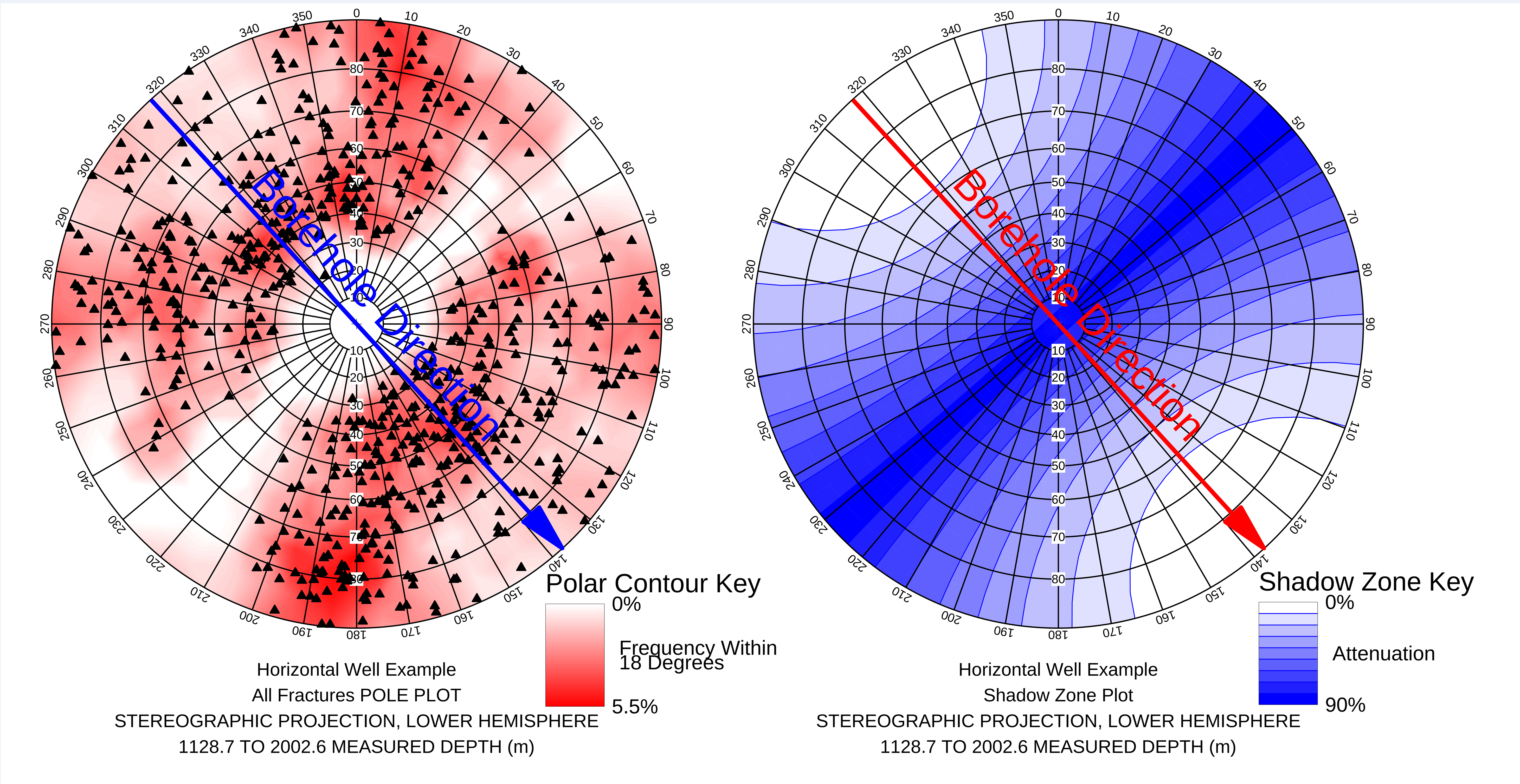
The angle between the borehole and fracture plane, β, has a strong effect on the number of fractures encountered relative to the number of fractures encountered perpendicular to fracture orientation.





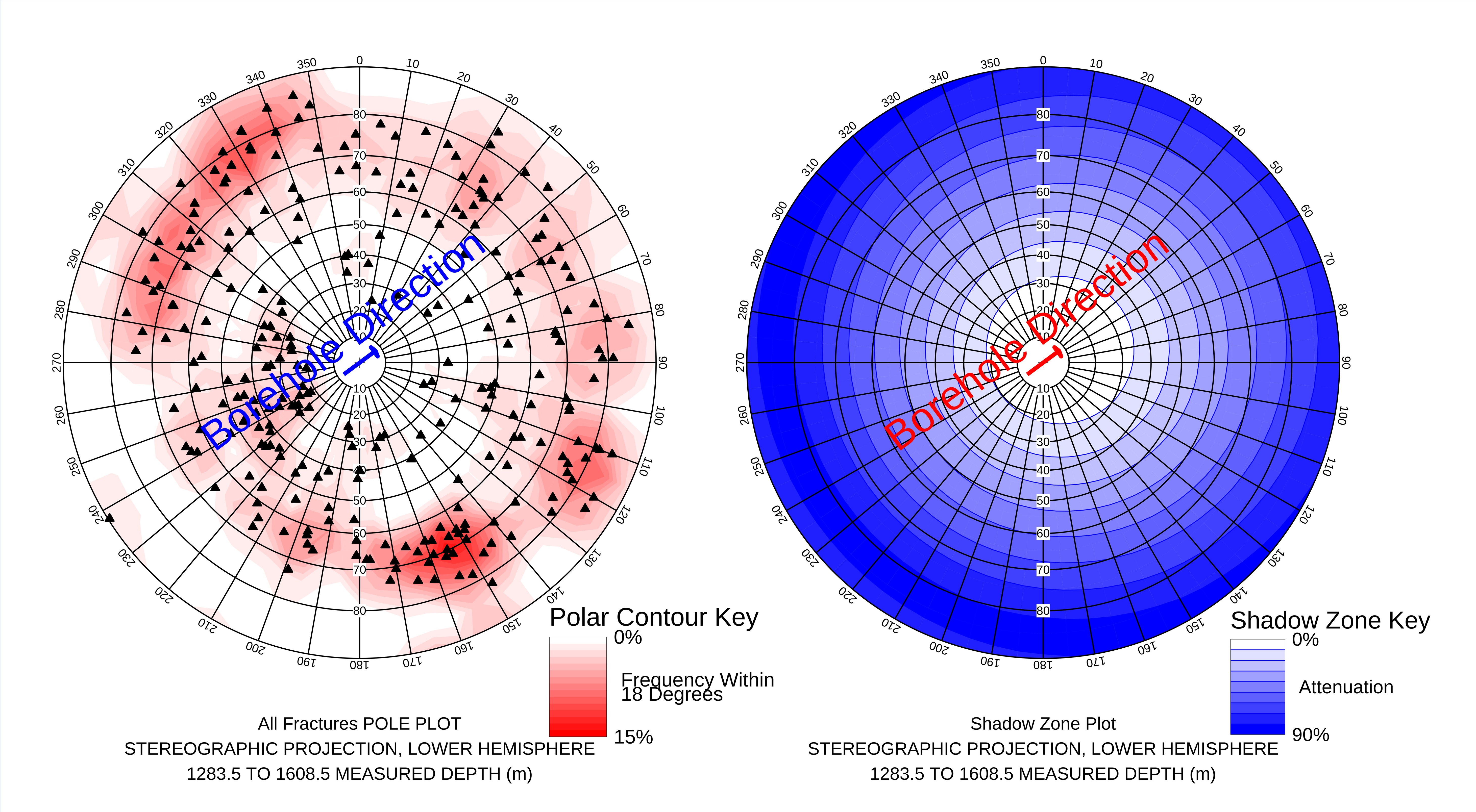
The shadow zone or "blind zone" (Terzaghi, 1965) causes the attenuation found on polar plots.

Horizontal-Borehole Shadow-Zone Plot

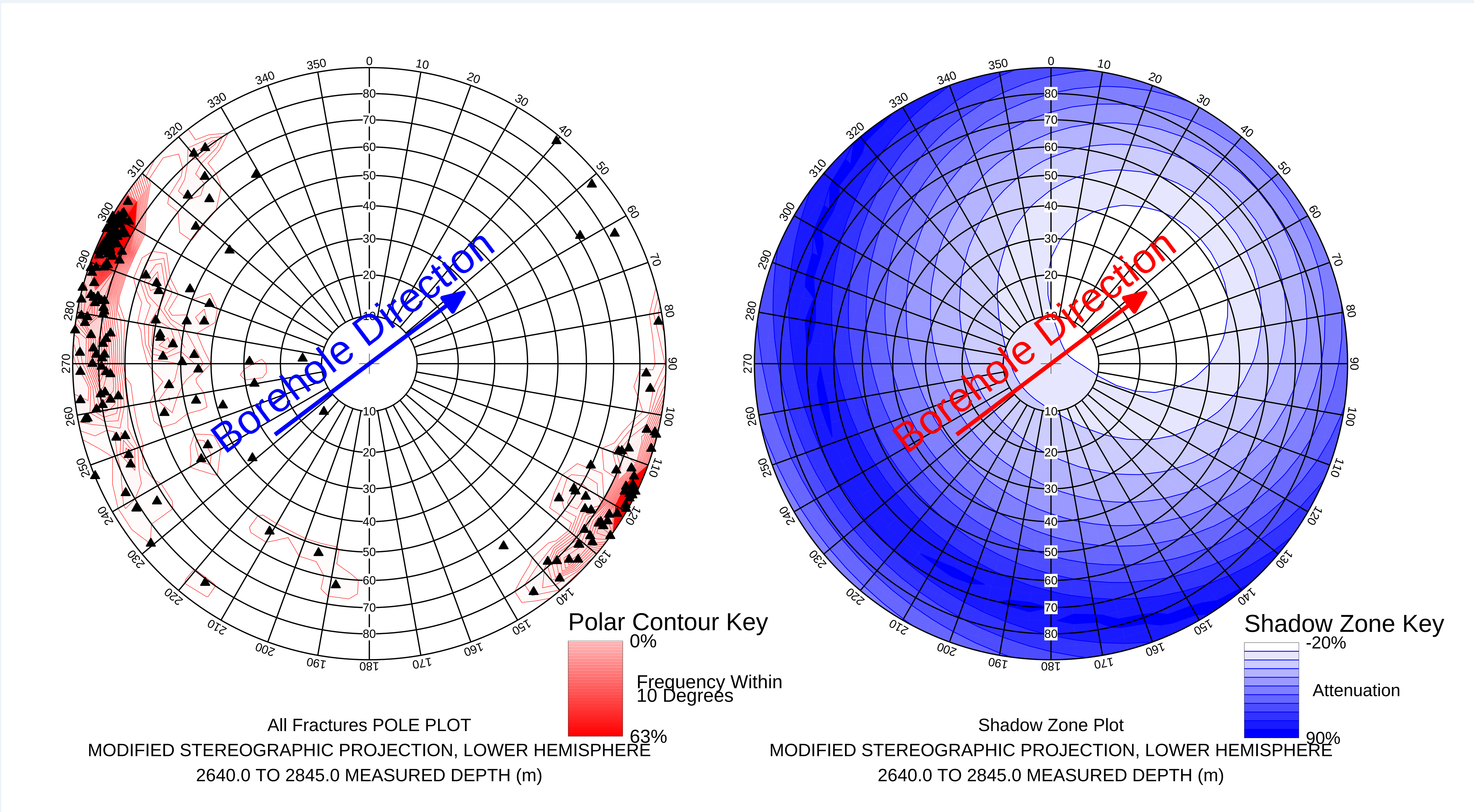


Panel 2. The bottom left hand plot shows fracture poles in a horizontal well. The bottom right handplot shows a shadow zone plot showing predicted attenuation as illustrated in the upper right hand plot.

Vertical-Borehole Shadow-Zone Plot



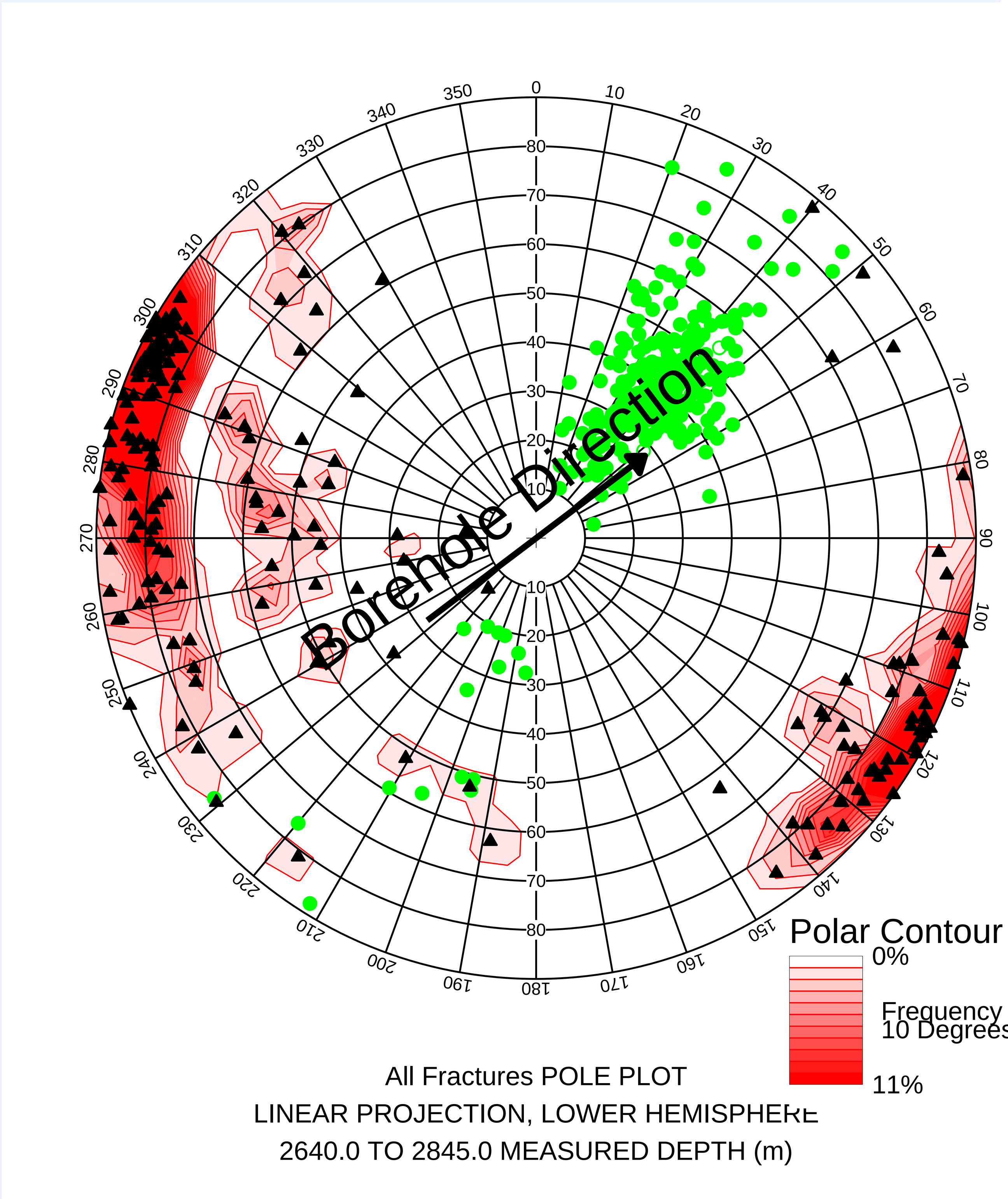
Inclined-Borehole Shadow-Zone Plot



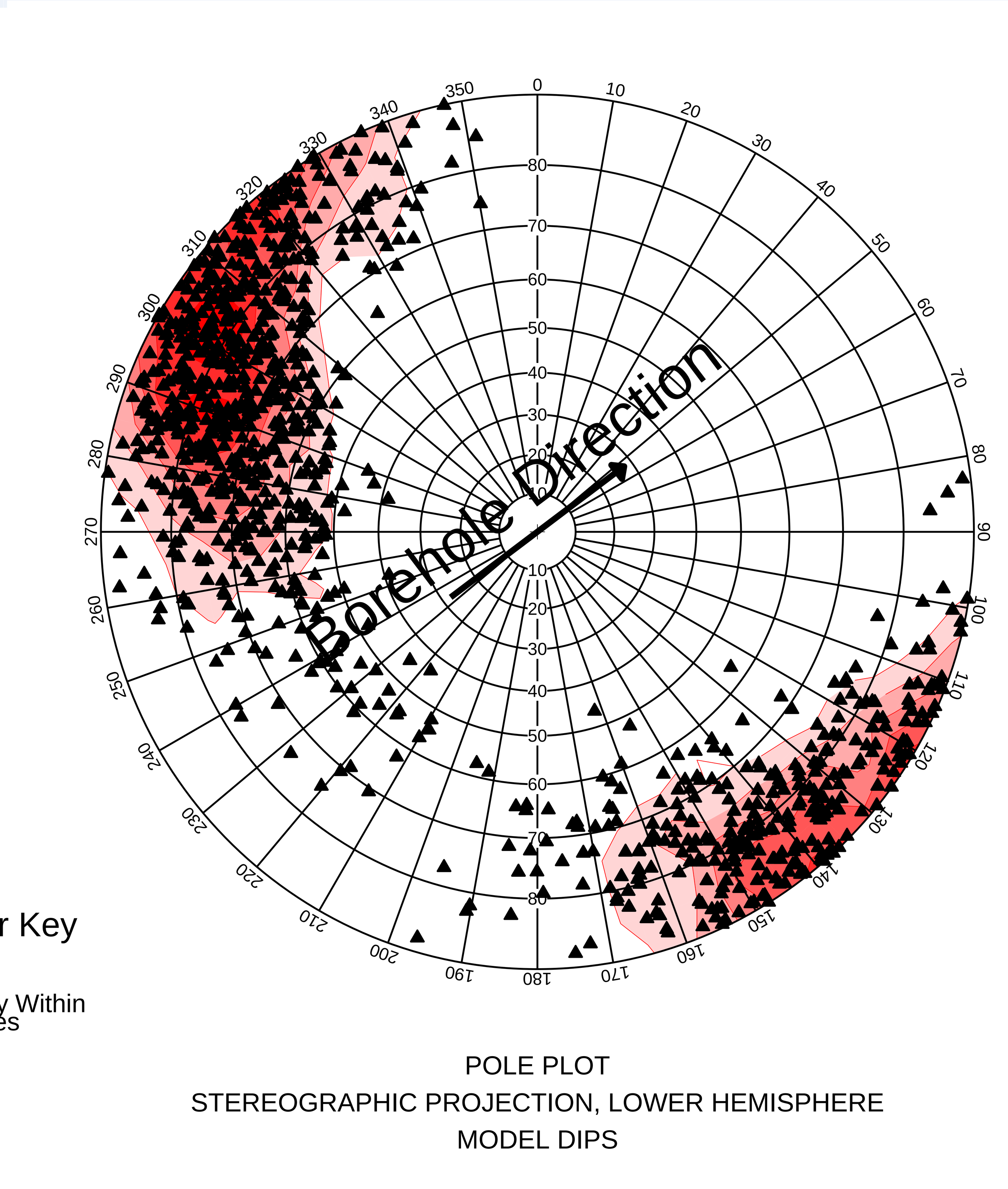
Panel 3. Top: An example of a near-vertical well with fracture pole plot on the left and shadow zone plot on the right. Bottom: A similar example to the top plots except the borehole is inclined. The well was drilled perpendicular to bedding in order to avoid hole problems caused by heavy fracturing.

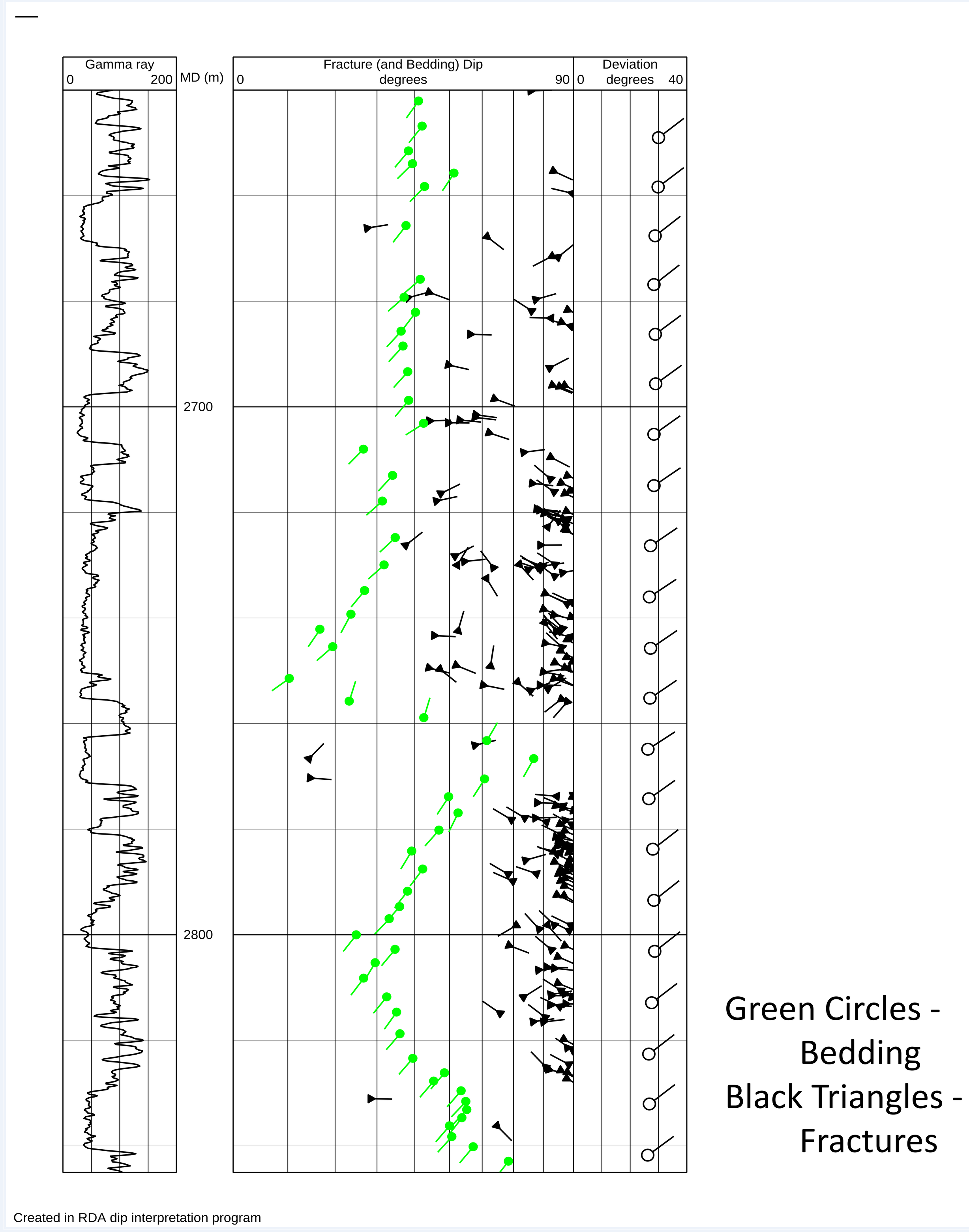
Modeling Attenuation Effects – Inclined Borehole

Original Data
~200 Fractures

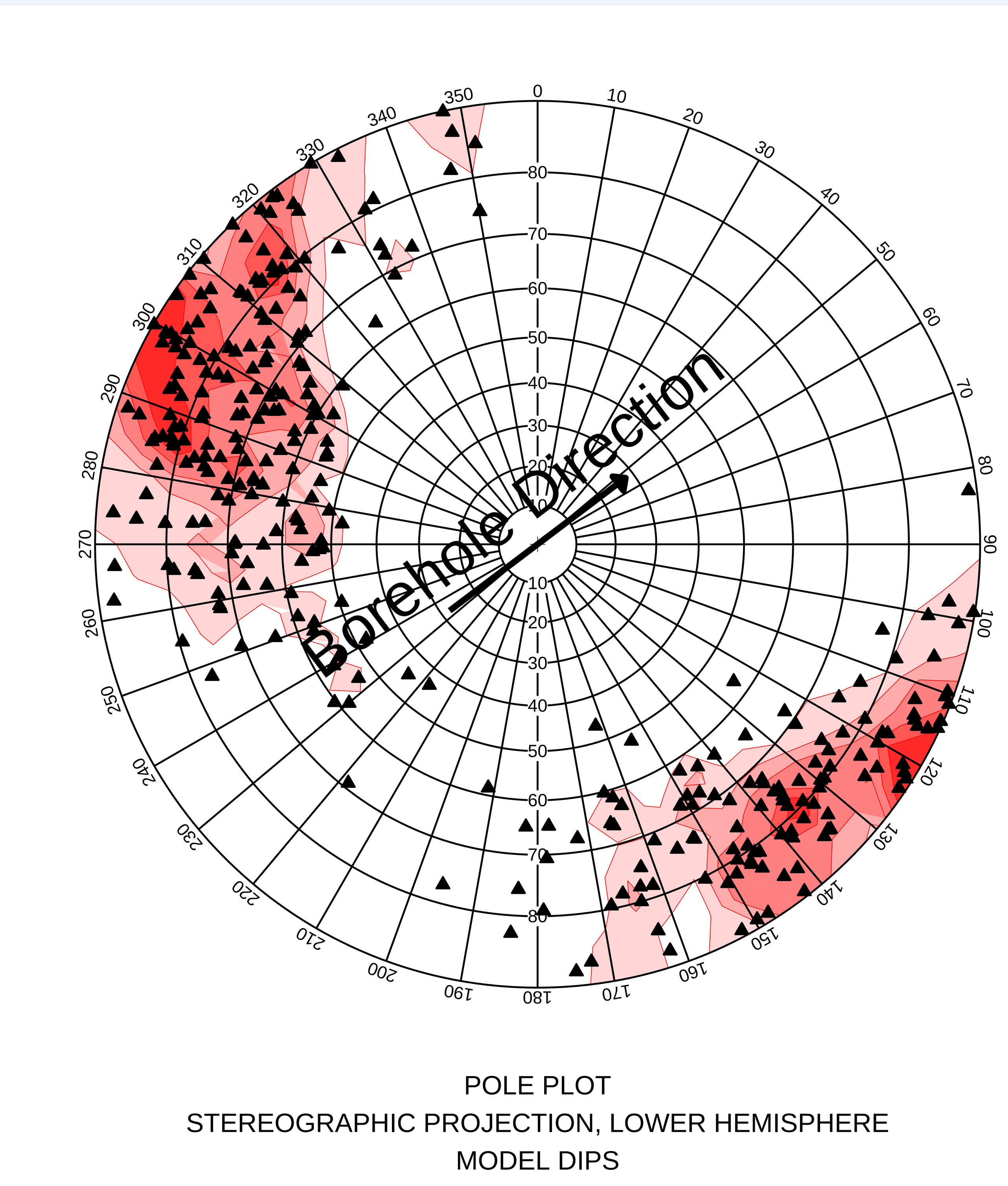


Generated Fractures
1000 Fractures

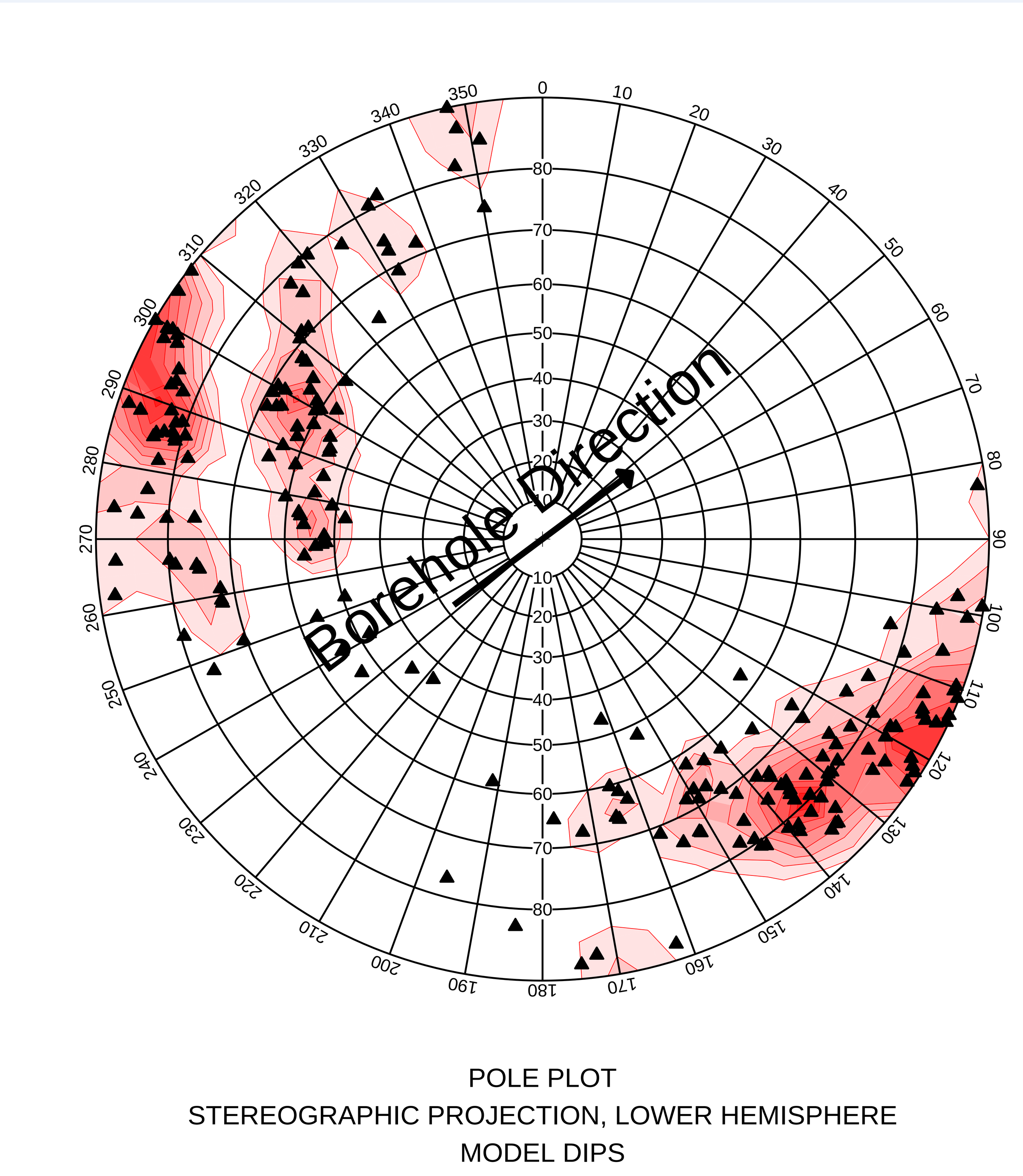




Attenuation
~300 Fractures



Attenuation and Induced Cutoff
~200 Fractures



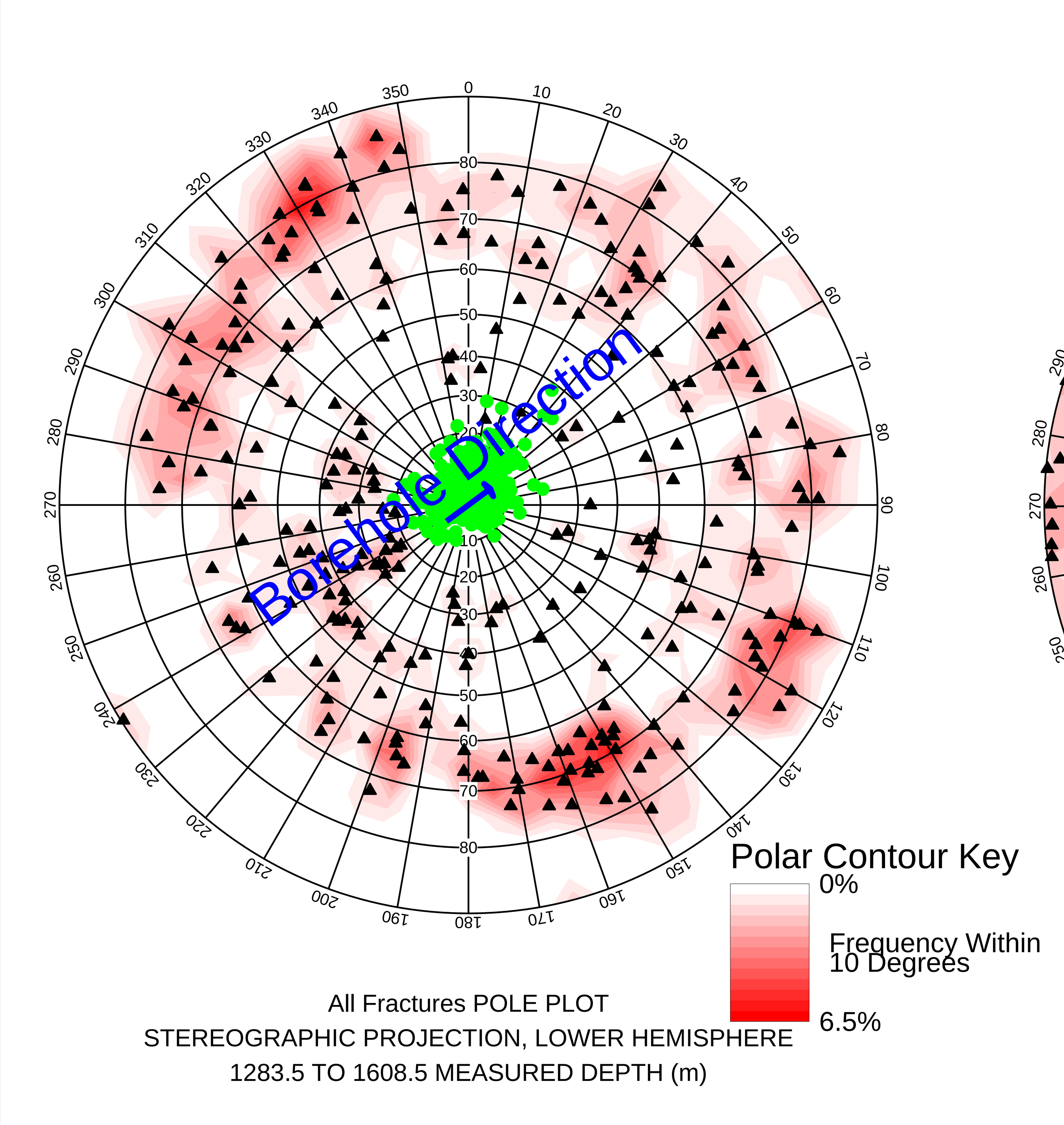
Modeling Parameters

1. Bimodal Joint Distribution
   - Dip Standard Dev. – 10º
   - Azimuth Std. Dev - 225º
   - Center Azimuth- 300º
   - Bedding Dip - 30º
   - Bedding Azimuth - 225º
2. Attenuation
   - Fracture Height - 1.3m
   - Fracture Length - 10m
   - Drilling-Induced Fracture Cutoff - 6.5º
3. Average Borehole Deviation
   - Inclination - 28º
   - Azimuth - 53º

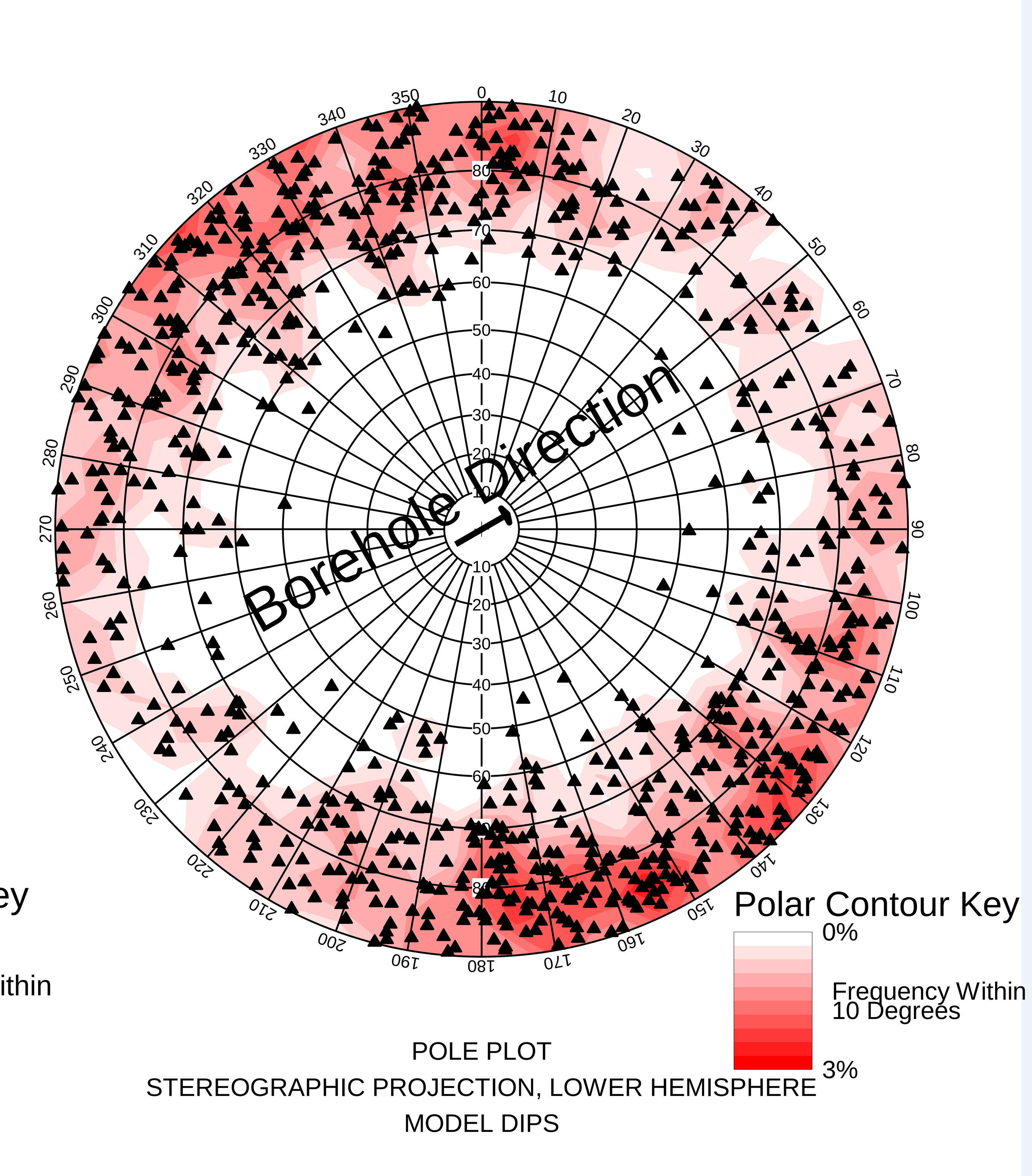
Panel 4: Model of the inclined borehole example in panel 3. The upper left plot is a plot of fracture and bedding poles, with beds in green. The upper right stereonet is a plot of fractures generated in order to derive the final, modeled plot on the lower right. The lower left plot has only attenuation applied. The lower right plot has attenuation applied and it excludes all fractures within 6.5º parallel to the borehole, mimicking the effect caused by the interpretation of all near-parallel fractures as being drilling-induced. The difference between the lower left and lower right plots shows the need of a correction to fracture density caused by the interpretation "filter".

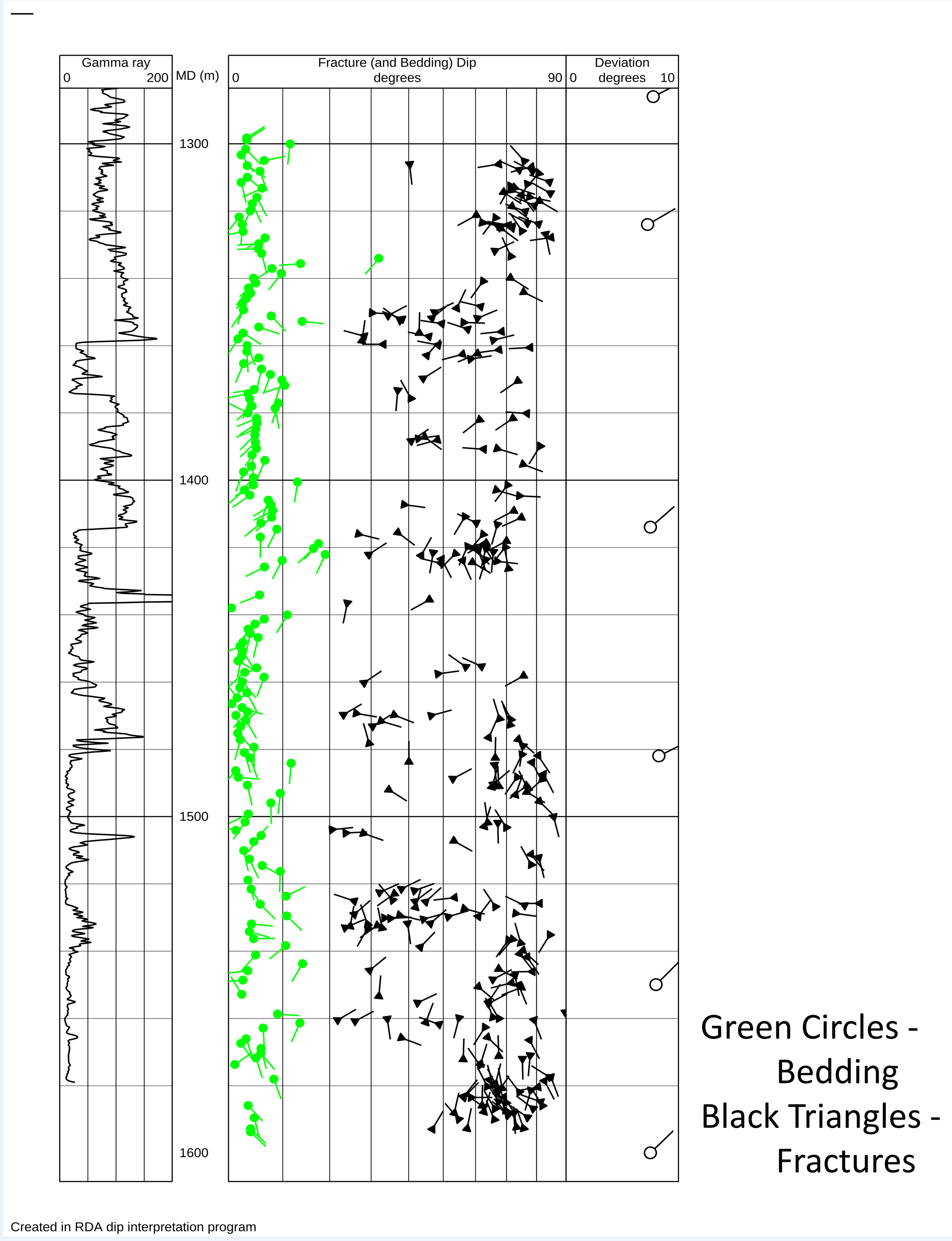
Modeling Attenuation Effects - Vertical Borehole

Original Data
~270 Fractures

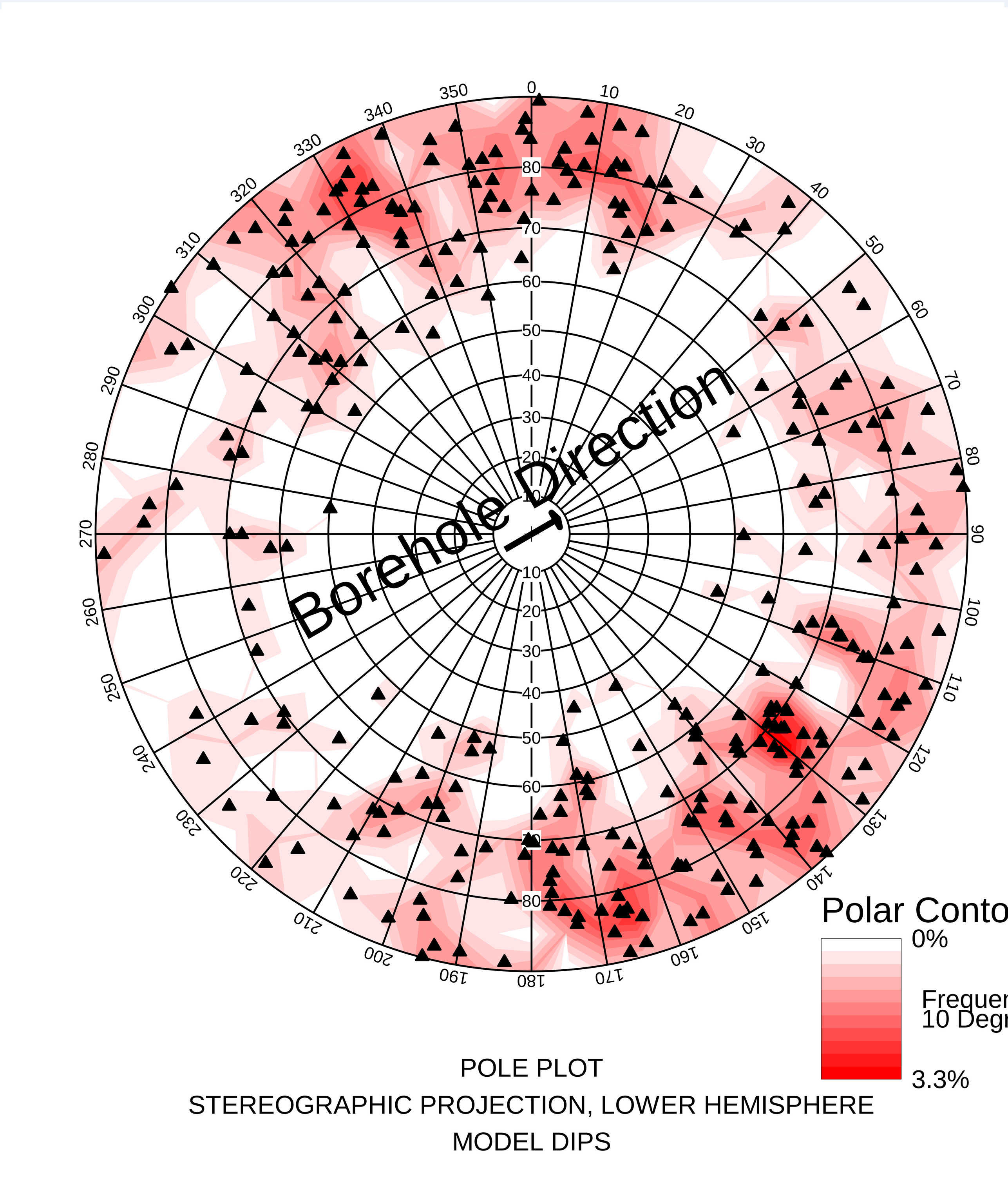


Generated Fractures
800 Fractures

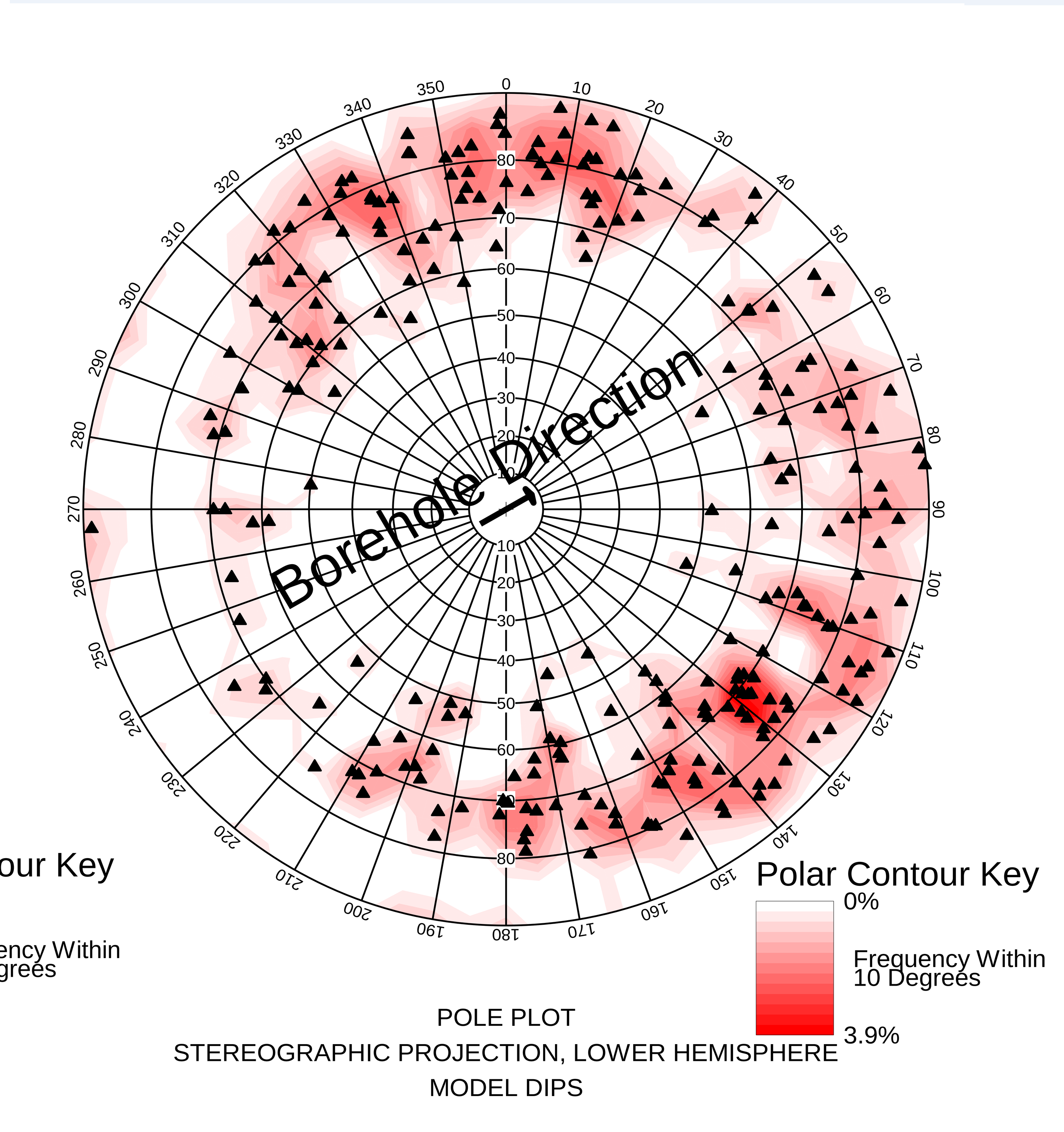




Attenuation
~310 Fractures



Attenuation and Induced Cutoff
~260 Fractures

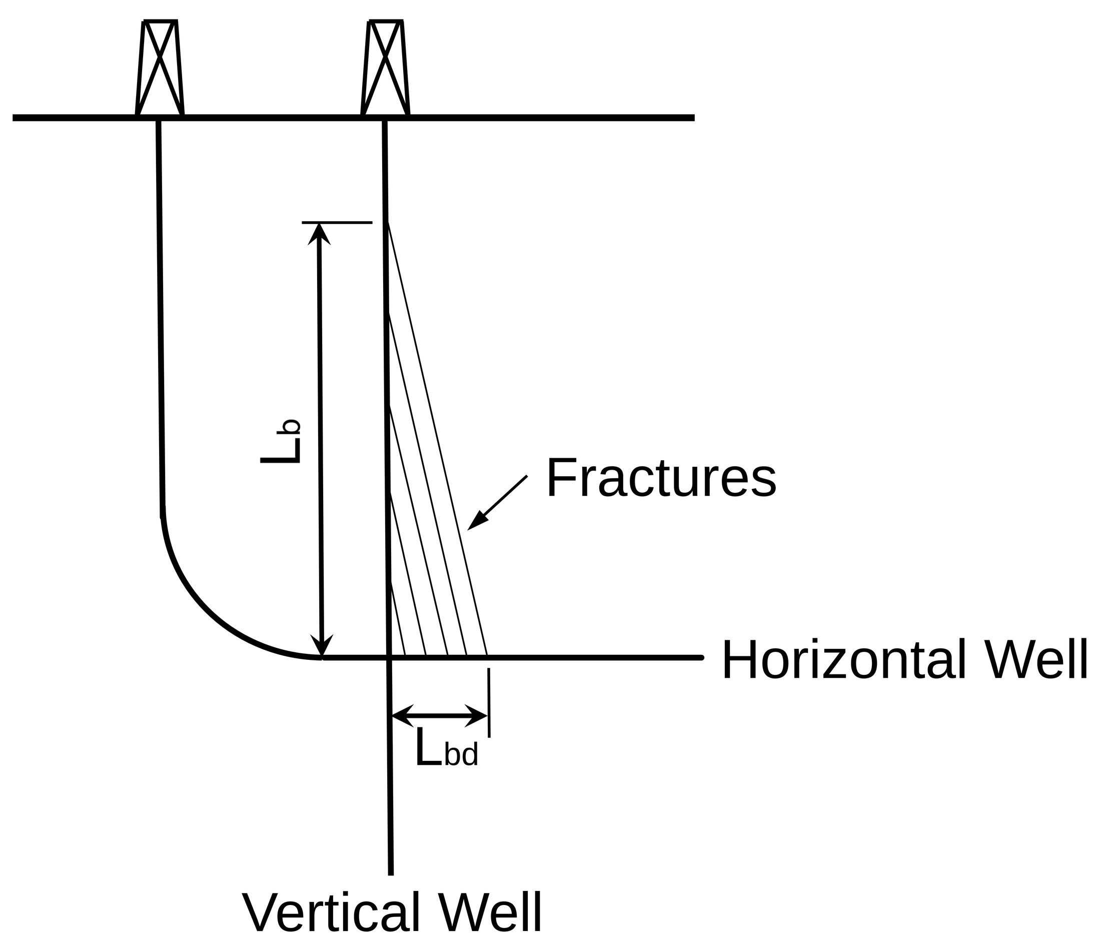


Modeling Parameters

1. Bimodal Joint Distribution
   - Dip Standard Dev. – 15°
   - Azimuth Std. Dev - 45°
   - Center Azimuth- 330°
   - Bedding Dip – 3.1°
   - Bedding Azimuth - 201°
2. Attenuation
   - Fracture Height - 1.3m
   - Fracture Length - 10m
   - Drilling-Induced Fracture Cutoff - 6°
3. Borehole Deviation (Averaged from Well)
   - Inclination - 8°
   - Azimuth - 60°

Panel 5. Same explanation as panel 4, except using the vertical borehole example.

Frequency Prediction



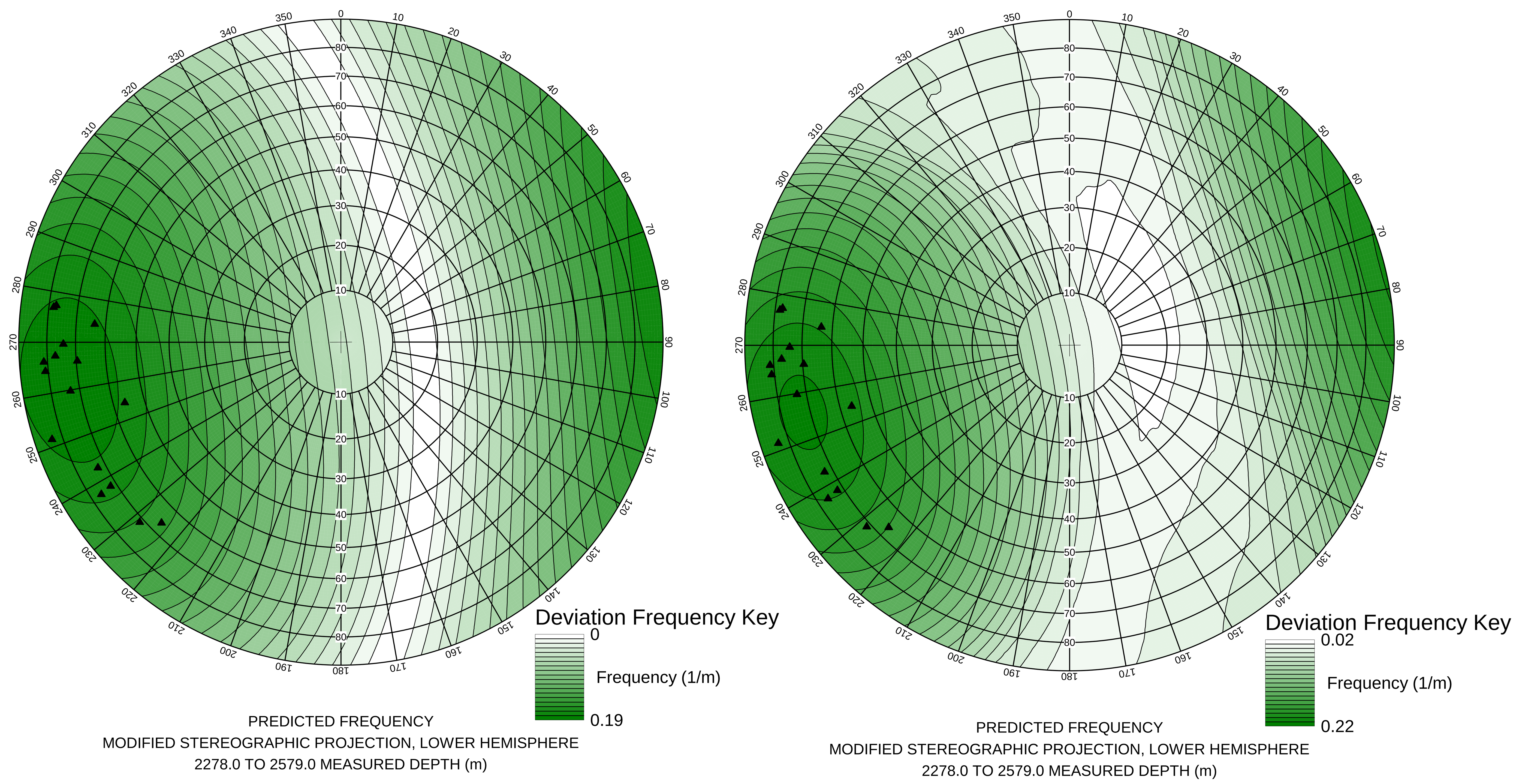
$$ {}_d = F\frac{C_{P32}}{C_{P32d}} $$

Fracture Set (Lower Left)

$$ F_d = F\frac{\sum_{i=1}^{n} C_{P32i}}{\sum_{i=1}^{n} C_{P32di}} $$

Multiple Fractures (Lower Right)

Deviation-Frequency Plots



C_{P32} is calculated by Priest (1993) method. In the right-hand plot, Priest's limit has been applied to the weighting.

Apparent Spacing

Vertical = $18.8m^{-1}$

NS Horiz. = $39.5m^{-1}$

EW Horiz. = $5.61m^{-1}$

Apparent Spacing

Vertical = $18.8m^{-1}$

NS Horiz. = $27.9m^{-1}$

EW Horiz. = $5.15m^{-1}$

C.I. = $0.01m^{-1}$

Panel 6. Deviation frequency plots using dips from a vertical well in the Montney Formation in British Columbia, Canada. The equations on top are derived from a paper, currently in review, on the calculation of fracture density (P_{32}) from fracture frequency (F). The variable C_{P32} is the correction factor for converting frequency into density.The lower plots are stereonets in which the fracture frequency from a vertical well has been projected at all possible deviation angles using the equations. To read the plots, choose a borehole deviation direction and read the frequency at that point. For example, on the left-hand plot, for anorth-south borehole trajectory, the frequency is about $0.025m^{-1}$. The apparent spacing is the inverseof frequency, which calculates to about 40m.

References

Terzaghi, R.D., 1965, Sources of errors in joint surveys, Geotechnique, v. 15, 287-304.

Priest, S.D., 1993, Discontinuity analysis for rock engineering, Chapman & Hill, 473 p.