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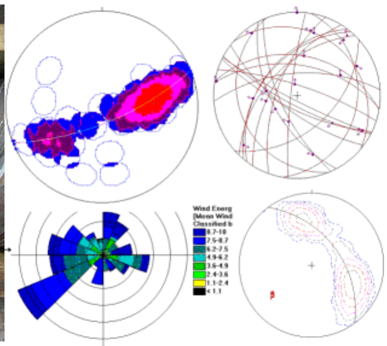
ORIENTED DRILLCORE: MEASUREMENT, CONVERSION, AND QA/QC PROCEDURES FOR STRUCTURAL AND EXPLORATION GEOLOGISTS

Last modified May 2023



TOPICS

- **Drillcore orientation types**
- **Drill core measurement procedures**
- **Geometrical relationships**
- **Using GeoCalculator to solve the geometry**
- **Interpolation of drillhole survey data**
- **Manual stereographic plotting procedures**
- **Statistical data bias**
- **QA/QC: Error detection and control**
- **Core Orientation scores**
- **Core shed layout**
- **Using classified and numeric stereographic projections in exploration**
- **Introduction to HCOV Global wrap-around beta angle protractor templates**

Note: A Chinese translation of the 2011 version of the manual can be found at:
http://media.wix.com/ugd/baa4fe_5e5652204599429db680545bcf4e20fe.pdf

The oriented drillcore procedures are also included in the Rod Holcombe text: “Mapping and Structural Geology in Mineral Exploration: where theory hits the fan”, see: https://www.holcombe.net.au/book/rodh-book.html

Contents

Oriented drillcore: Measurement, conversion, and QA/QC procedures for Structural and Exploration Geologists 1
- Topics 1
- Drillcore orientation types 3
  - Unoriented drillcore 3
  - Fully-oriented drillcore 3
  - Partially-oriented drillcore 3
  - Drillcore angle conventions 4
- Measurement procedures in Oriented core 5
  - Measurement of alpha angle 5
  - Measurement of beta angle 6
  - Measurement of surfaces parallel to the core 9
  - Measurement of lines in core 10
- Measurement in Partially-Oriented core 11
- Geometrical relationships in Oriented core 12
- Geometrical relationships in Partially-Oriented core 13
- Using GeoCalculator to process drillcore data 15
  - Using GeoCalculator with Oriented core 15
  - Using GeoCalculator with Partially-Oriented core 15
- Manual stereographic plotting of Oriented core 17
  - Procedures 17
  - Details of step 2 and 3: preservation of sense of beta direction and sense of counting of delta angle 18
- Other Calculations 19
  - Interpolation of drillhole surveys 19
  - Correcting structural data for subsequent changes in hole surveys 19
- QA/QC: Error detection and control 21
  - What is well-oriented core? 22
  - Quality control: A core orientation rating for an entire drillhole 23
  - Sources of error and minimisation of error 24
- Core shed layouts 34
- Orientation data analysis using Classified Stereographic plots 35
- Wrap-around protractors for Oriented drillcore measurements 38
- About The Author 39

DRILLCORE ORIENTATION TYPES

Unoriented drillcore

During core drilling, runs of core up to about three metres long are extracted from the core barrel. The extraction process rotates the core randomly, so that once the core is laid out in core boxes its original orientation is lost, although the orientation of the core axis is generally known. Various down-hole surveying techniques are available for this, and the common usage of 3-D modelling software has lead to holes being generally very well surveyed.

Fully-oriented drillcore

Various methods (mechanical and optical) are available to identify the orientation of specific sections of core during drilling. Commonly the process involves identifying the lowermost point ('bottom mark') on the top face of what is to be the next run of core. After the core is extracted it is reassembled as far as possible and the 'bottom mark' used to subtend an orientation line along the core (known as the 'orientation mark' or 'ORI line'). This line is used to orient all other features in the core.

Orientation line on core. The barbs point 'down-hole' – that is away from the collar, even if the hole is directed upwards from underground.

Many methods use gravity to find the lowermost point and in these holes core orientation is only feasible in holes with a non-vertical plunge (generally <70). The orientation mark, along with local knowledge, allows the structures in the core to be uniquely oriented in space.

The most common practice is to subtend the 'orientation mark' from the 'bottom mark', and thus this line represents the lowermost line along the core ('bottom mark', 'BM'). Less commonly, the orientation line is drawn along the top of the core as a 'top mark'.
The orientation of structures in oriented core can be determined in two ways:

1. by reorienting the core using either a bucket of sand or a mechanical jig and measuring the structures as you would in outcrop;
2. by measuring several critical angles on the core and then using either software or stereographic projection to calculate the true geological orientation. The bulk of this document concerns these types of measurement and plotting procedures.

Partially-oriented drillcore

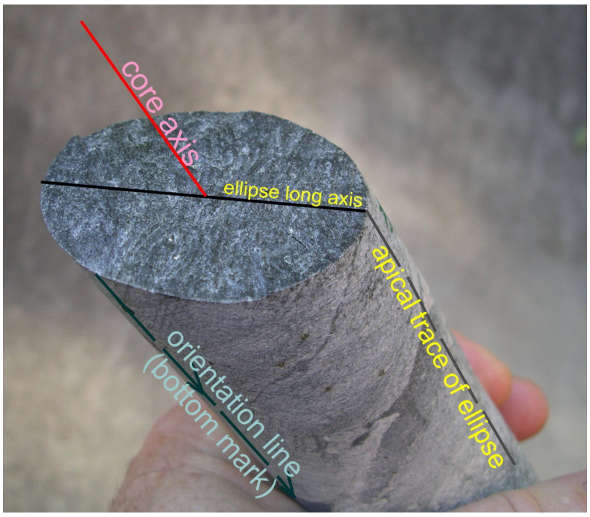
If nothing else is known about the orientation of a planar bedding surface (for example) visible in unoriented core, it would require three differently oriented drill holes to solve the geometrical problem to determine the orientation of constant dipping, planar bedding planes. However, if we know something else about the plane, such as its **general** dip, or **general** strike direction then we would only need two drill holes. If, however, we can be specific about one or other of these directions then we may only need a single drill hole to solve the orientation problem.

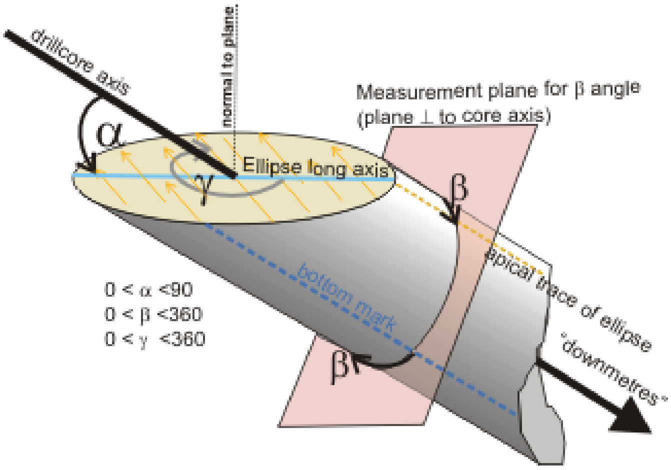
Thus '**Partially-oriented**' core is core in which a local reference plane whose orientation is well known (such as bedding, cleavage, etc) can be recognised in the core. Only partial knowledge of the orientation of this reference plane need be known (e.g. dip direction/strike, or even just the local fold axis) in order to obtain the orientation of the unknown plane. Commonly the calculation produces two solutions, and other knowledge, such as whether the structure is shallowly or steeply dipping, may be required to solve the ambiguity.

Software, such as **GeoCalculator** (https://www.holcombe.net.au/software/) can be used to convert angles measured from such core into geographical structural readings.

Drillcore angle conventions

Various conventions are used to reference angles in oriented or partially oriented drill core.





All planes intersecting drill core have an elliptical cross-section in the core. The '**apical trace**' of this ellipse is the line subtended along the core from one end of the long axis, formed by the intersection of the plane that contains the ellipse long axis, the ellipse normal, and the core axis. Similarly, the 'apical trace' of a Line, is defined by the intersection with the core of a plane containing the core axis and parallel to the line (i.e. passing through the central axis of the core).

Measurement conventions used in the discussion and protractor templates here are:

- **alpha angle:** the acute angle between the core axis and the long axis of the ellipse (0-90°).
  (Alpha angles can also be used with **lines**, where the line passes through the centre of the core (or can be imagined doing so). Then the alpha angle is: the angle between the core axis and the **line**).

> While Greek letter naming conventions are universal for drillhole data, there has been inconsistency in the actual letters and usage. The alpha-beta letter conventions defined here are those currently in common usage (although an equivalent delta, alpha convention has precedence in the literature).

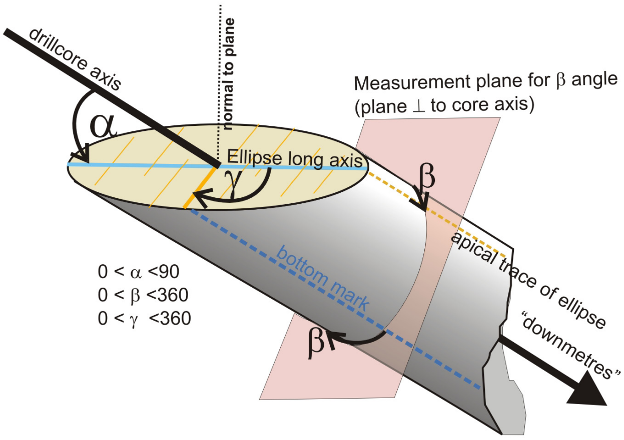
- **beta angle:** the angle between a reference line along the core and the ellipse apical trace measured in a clockwise sense (0-360°) looking along the core **toward the end-of-hole**. (Note that in core that is drilled upwards, the clockwise sense is still taken looking toward the end of the hole, even though this mis now physically looking upwards). In 'oriented core', the reference line is the 'orientation mark' or 'bottom mark' and the beta angle of the apical trace of the ellipse is measured clockwise from this line.
  In 'partially oriented' core the reference line is the apical trace of the reference plane ellipse, and the beta angle is the angle between this apical trace and the apical trace of an unknown plane or line.

- **gamma angle** of a line lying within a plane: angle, measured within the plane, between the long axis of the ellipse and the line. Different conventions are in use (360° clockwise, ±180).
- **core axis plunge and plunge direction** Note that in this manual, **plunge**, is used to refer to the inclination angle of a drillhole. This is the correct structural term for the inclination of any linear feature (such as a drillhole). However, due to careless nomenclature introduced by pioneers of orientation software, the term **dip**, reserved for planar objects, has come to be synonymous with **plunge** within the minerals industry.

MEASUREMENT PROCEDURES IN ORIENTED CORE

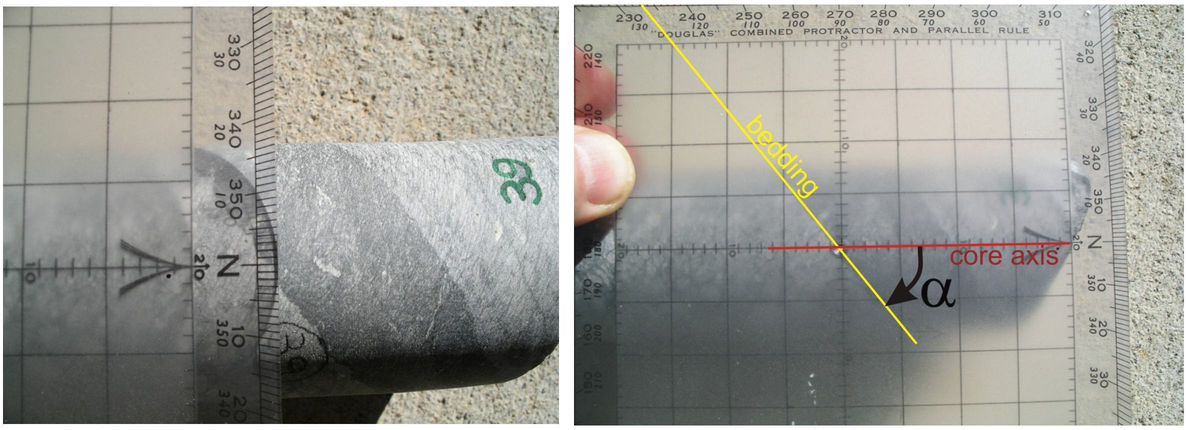
Two techniques are common for obtaining the geological orientation of structures in core:

- Reorienting the core in sand or a mechanical jig and directly measuring the structures using normal field outcrop techniques. This procedure is straightforward and will not be described further;
- Alpha-beta-gamma measurement of: (i) α – angle between plane and core axis; (ii) β - angle from orientation line measured in a clockwise sense around the core; and (iii) γ - angle from ellipse long axis to a line lying in the ellipse plane (also measured in a clockwise sense looking toward the end-of-hole).

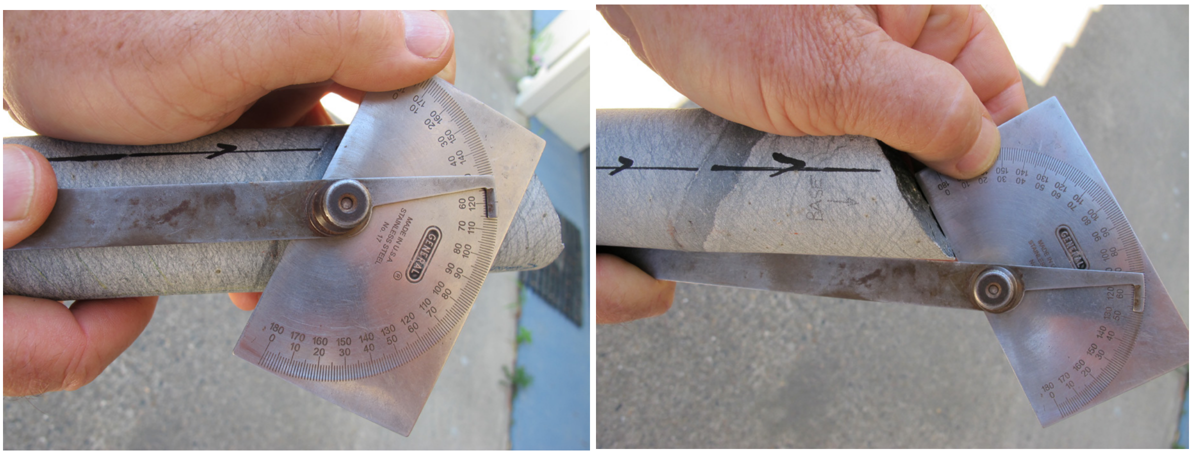


Measurement of alpha angle

1. Direct measurement by rotating the core until the surface to be measured appears to make a minimum angle with the core axis. This procedure is the easiest method.

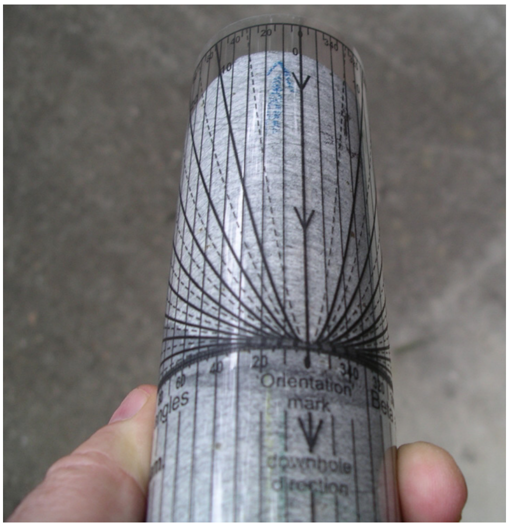


Above: *Square (Douglas) protractor used to measure alpha angle of bedding*
Bottom: *Metal pivoting-arm protractor used to measure alpha angles of bedding (left) and cleavage (right). This type of protractor is by far the most precise (direct measurement to 1 degree) and I have found it very easy to use.*

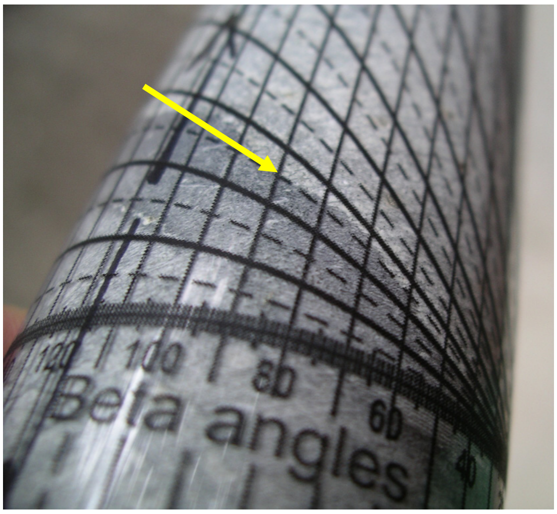


Metal pivoting-arm protractor used to measure alpha angles of bedding (left) and cleavage (right). This type of protractor is by far the most precise (direct measurement to 1 degree) and I have found it very easy to use.

2. Using templates and devices that directly measure the alpha angle in 3-D. These tend not to be as precise as a pivot-arm protractor for measuring alpha angle. The one shown below use the alpha angle lines on the wrap around protractor template included with this manual, printed onto transparent film.



Base of the protractor alpha angle curves aligned with the base of a bedding ellipse.



Alpha angle of 65º read from trace of bedding parallel to alpha curve.

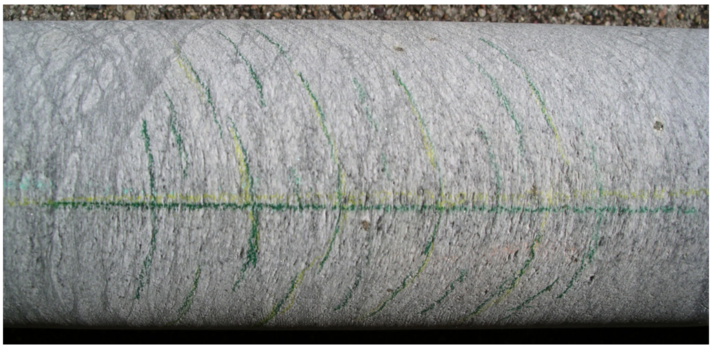
EZY-logger core goniometer

Kenometer jig

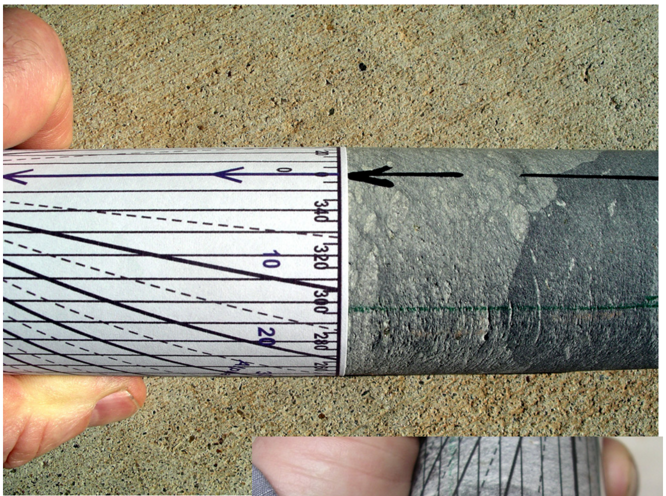
Measurement of beta angle

1. Mark the apical trace of the plane ellipse along the core.
   Two possible conventions are in use: to use the down-hole* end of the ellipse, or (less commonly) to use the up-hole end of the ellipse. If the convention used is to take the bottom of the ellipse then ensure that this line joins the lowest point of curvature of the plane in the core.

   If the surface to be measured is a fine cleavage, then it is easiest to mark cleavage traces around the core to determine the points where the fabric is perpendicular to the core axis.



2. Hold the core such that you are looking toward the base of the hole (EOH). The beta angle is the angle measured clockwise between the orientation mark and the apical trace of the plane.
   Accurate measurement of the beta angle can be made using either specially constructed circular protractors or, more simply a flexible wrap-around protractor printed on paper or heavy transparent film such as the ones supplied with this document. (Transparent film is best). Orient the wrap-around protractor with the 0 degree line on the orientation mark and the arrows on this zero line pointing down-hole*.



   In the example the beta angle between the black orientation line (with down-hole arrows) and the apical line of bedding (green) is 295º.

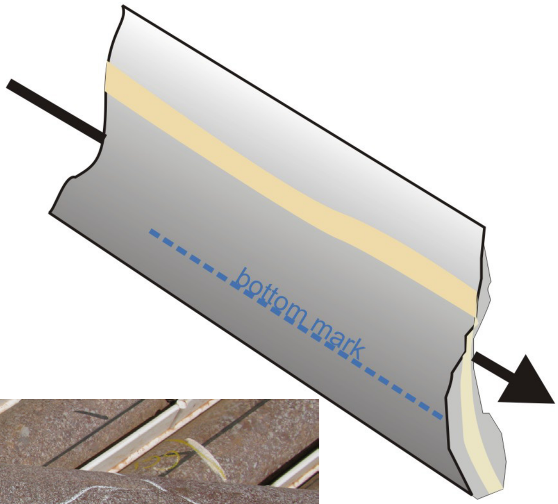
   *'***Down-hole***' means in the direction away from the start (collar) of the core, irrespective as to whether that is geographically oriented upward or downward. This is sometimes called the 'down-metres' direction.

Using a protractor printed on transparent film it is easier to see the lines drawn on the core.

Rigid jigs, such as the Ezi-logger and Kenometer jigs shown previously are becoming popular but require a very snug core fit to minimise beta angle errors. The EZY-logger jig follows the standard beta angle definition by lining up the beta angle scale zero with the orientation line on the core, and then measuring the clockwise angle (looking downhole) to the end of the ellipse on the core. The Kenometer jig requires some though by the logger as it lines up the zero on the beta angle scale with the end of the ellipse and then measures the **anticlockwise** angle to the prientaion line on the core. The beta angle is still the same in both cases.

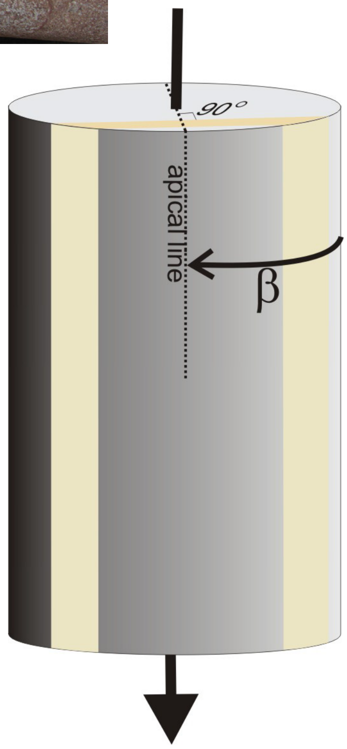
In all cases it is important to ensure that the correct end of the ellipse is consistently used to obtain the beta (or gamma) angle. It doesn't matter whether the site convention is to use the up-hole end of the ellipse or the down-hole end, provided it is uniformly applied (and the convention recorded in any data records). The Kenometer jig requires particular attention when defining which end of the ellipse to use. It is designed to hold the downhole end of the core upwards in the jig, so that the down-hole end of the ellipse will now face upwards in the jig.

Measurement of surfaces parallel to the core



As described in a later section, bias is commonly introduced by avoiding measuring planes that are parallel to the core axis. Presumably the reason such measurements are skipped is because there is no well-defined ellipse.

If the surface is perfectly parallel to the core axis then the alpha angle is zero. In the example below, although the bedding undulates a little and is offset by small faults, it is effectively parallel to the core axis.



To estimate the apical line in order to measure the beta angle:

1. Identify the orientation of a line lying in the surface perpendicular to the core axis
2. Let this line orientation pass through the core axis
3. Where the line through the core axis meets the core surface draw a line parallel to the core axis. There are two possible such lines on either side of the core.
    - If the surface is truly parallel to the core axis then either of the two axis-parallel lines can be used as the apical line for measuring the beta angle. (That is, for zero alpha angle, a beta angle of 90 is exactly the same as a beta angle of 270).
    - If the surface is slightly inclined (alpha angle is not zero) then choose the axis-parallel line that would project down to meet the bottom of the ellipse if it could be seen. Estimate the alpha angle (generally 0-3° for this scenario).

The simplest procedure is when the surface to be measured can be seen on the end of the core segment and this end break is perpendicular to the core axis (as shown in the diagram).

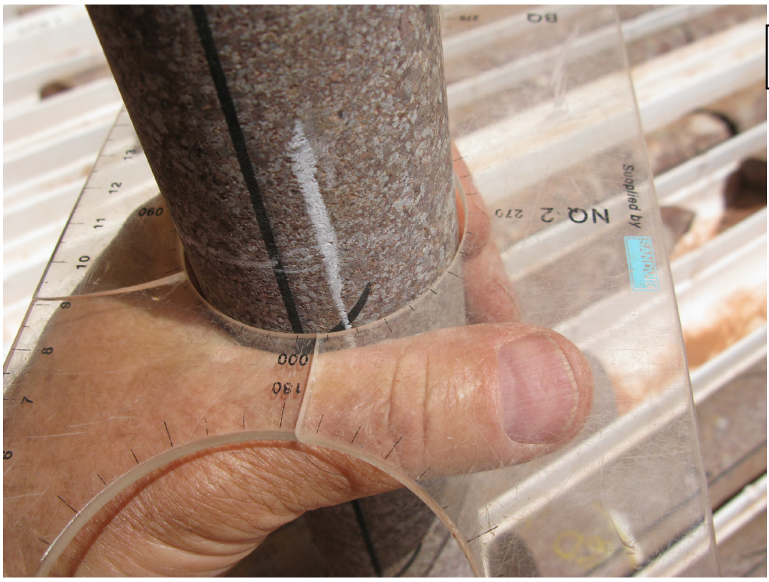
It is only slightly more complex when the end section cannot be accessed:

- Identify two equivalent points on the core surface that would lie on a line perpendicular to the core axis
- Using a beta angle protractor, measure the absolute angle between the two points around the core circumference
- Identify the point on the circumference that divides this angle by two and draw a line parallel to the core axis. This line is one of the two possible apical lines. The other is on the core diametrically opposite. As above, if the alpha angle is zero choose either line. If the alpha angle is

non-zero then select the line that would subtend to meet the bottom of the ellipse if it could be seen.

Subdividing the angle between opposite points on the plane.
Here a cut-out template is in use for measuring beta angle.

Marking the apical line

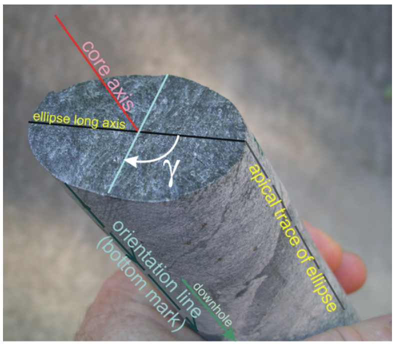


Measuring the beta angle

Measurement of lines in core

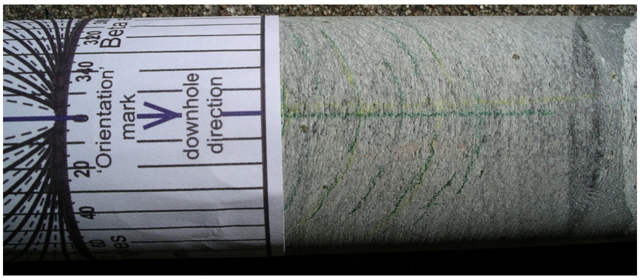
Two procedures can be used to measure lines in oriented core:

1. Treat the line as if it were the long axis of an ellipse and measure its alpha and beta angles. To do this you must subtend the line through the centre of the core and mark the apical line along the core from where the end of the subtended line. Proceed to measure the alpha and beta angles in the same way as for a plane.
2. Measure the gamma (γ) angle of the line within a plane that has already been measured. Ensure that the same conventions used to identify the ends of the ellipse long axis are used. That is, if the convention in use is to measure beta angles to the down-hole end of the ellipse, then use the down-hole end of the ellipse to measure the gamma angle.
   Two conventions are in use for the gamma angle:
    1. +ve (clockwise) or –ve angle (0-180) from the ellipse long axis;
    2. 360 clockwise angle (preferred as it is a single unambiguous number)



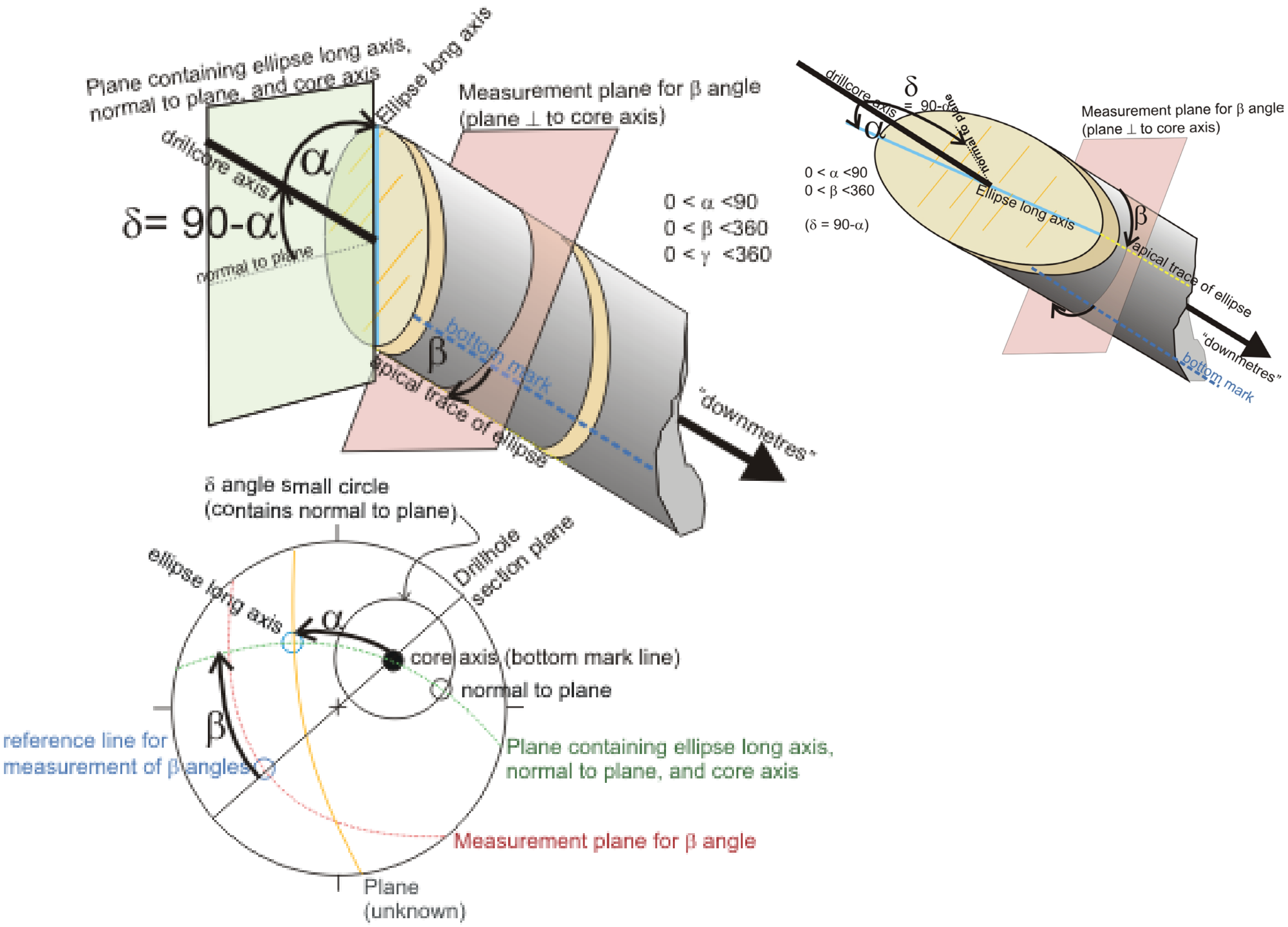
MEASUREMENT IN PARTIALLY-ORIENTED CORE

In partially oriented core the orientation mark is the apical trace of a reference plane whose orientation is known or partly known. The only difference to the procedures described for oriented core is that of using this reference plane apical trace from which to measure beta angles of other planes.



Although the calculations can be performed using a precise reference plane orientation, a more robust procedure is to record the alpha angle of the reference plane ellipse, and use only its dip direction to define it. The calculations then use the dip direction to calculate the most likely dip angle, and from there calculate the orientation of the other unknown planes and lines.

GEOMETRICAL RELATIONSHIPS IN ORIENTED CORE

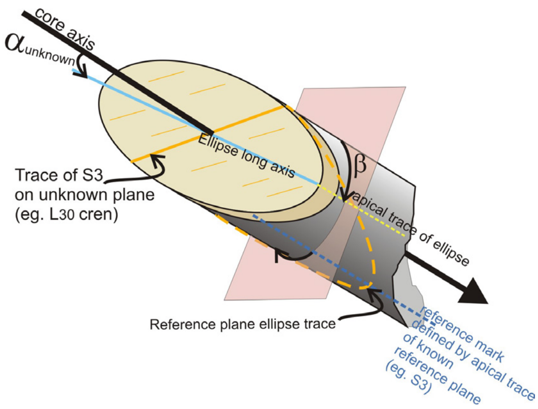


The stereo diagram shows the geometrical relationships used to solve oriented core problems. Note that the normal to the plane forming the ellipse lies somewhere along a small circle with an opening angle of 90-α (= the angle δ, in the figure above). The critical relationship is that the plane containing the long axis of the ellipse and the core axis also contains the normal to the ellipse plane. Finding this normal is the principal solution of most oriented core calculations. The stereographic projection procedure is outlined later in this manual, but in general the solutions are obtained by spreadsheets or computer packages such as our GeoCalculator (https//www.holcombe.net.au/software/).

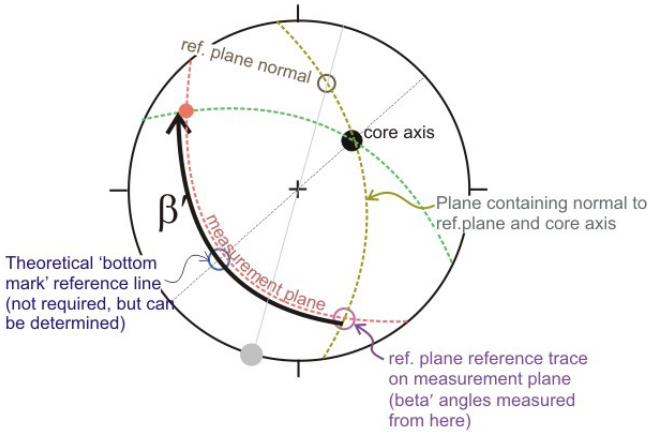
An important construction plane is the **measurement plane**, normal to the core axis. Because beta and gamma angles commonly use 360-degree clockwise conventions, care must be taken during manual calculation to preserve the upward or downward sense of the line or ellipse axis. Although the direct stereographic solution is shown later, a visually unambiguous way to preserve these line senses, is to construct the planes relative to a vertical axis, and then rotate the axis, and the solution, into its true orientation.

GEOMETRICAL RELATIONSHIPS IN PARTIALLY-ORIENTED CORE

Techniques using **partially-oriented** core are not generally described in the structural literature, yet they provide a powerful tool to unravel structure from old, unoriented, core, or to extract structural information from the unoriented parts of oriented core, using the orientations found in the oriented parts. The critical factor is that a specific, relatively planar, structural fabric can be recognised throughout the core. This is called the **reference plane**, and the apical trace of its ellipse is used as the ‘orientation mark’ for all core beta angle measurements.



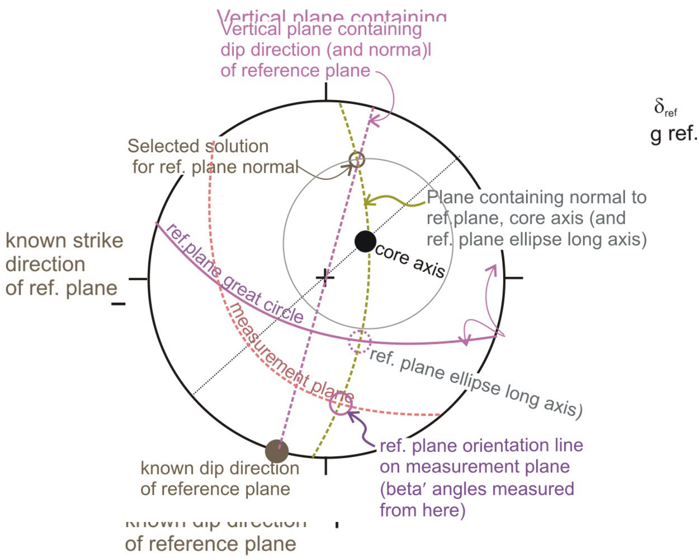
The algorithms for solving **partially-oriented** core are equivalent to using the known orientation of the reference plane to back-calculate where the theoretical ‘bottom mark’ would have been on the core, relative to the apical trace of the reference plane ellipse long axis. Thus, the orientation of any other unknown plane can be calculated as for the ‘oriented core’ procedures above.



The accuracy and confidence of results using the **partially-oriented** core technique relies strongly on how well the reference plane orientation is known. Precision is best when the reference plane normal is at a high angle to the core axis (i.e the alpha angle of the reference plane ellipse is large), but at very high alpha angles it is difficult to define the ellipse long axis.

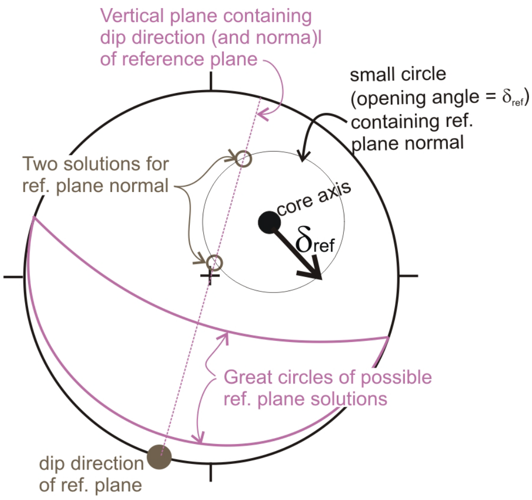
Commonly the strike or dip direction is better constrained than the actual dip of the reference plane. Or the orientation of a cylindrical (straight) fold axis might be well-constrained, although the orientation of the reference plane is quite variable. In most instances, the full orientation of the reference plane can be calculated provide that the alpha angle of the reference plane is also measured. The drawback is that, in some instances, there are two solutions for the full orientation of the reference plane and a decision must be made as to which is most likely.

The figure summarises the geometrical relationships used to determine the full orientation of a reference plane given only its dip direction. We know that the normal to the reference plane lies in the small circle with opening angle of 90-alpha (the delta angle). The critical point is to find another line in the plot that also contains the normal. One is the vertical plane containing the dip direction (i.e the plane normal to the strike). Another, not shown here, is the pi-girdle



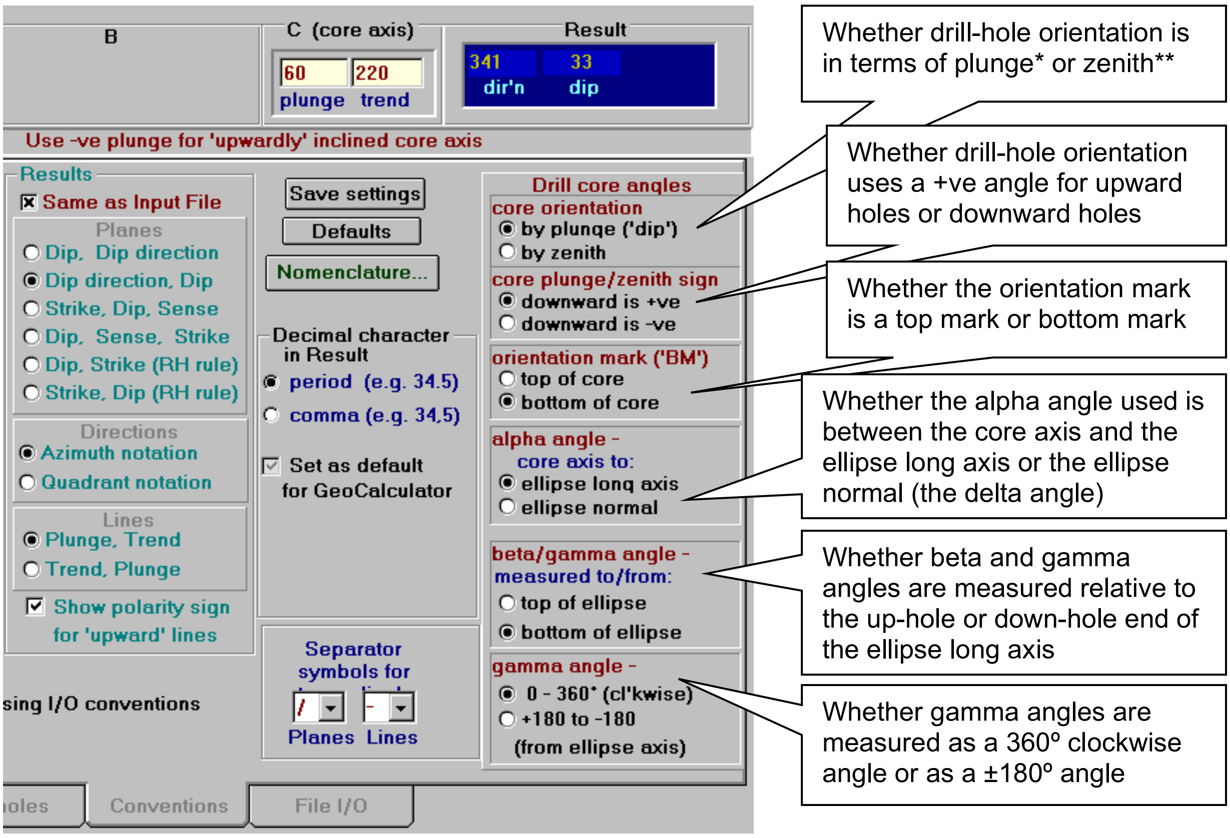
plane normal to a cylindrical fold axis. Note that, except in the tangential case, there will always be two solutions for the normal and we need to know something else about the orientation of the reference plane in order to choose the correct one. The simplest situation is to use the dip direction. For example, in the diagram above the only correct solution is the great circle with a southerly dip direction (Figure right), and from that the remainder of the geometry can be calculated as described for oriented core in a later section.

Two ambiguous solutions can occur (Fig. right); particularly when the small circle is small (the alpha angle is large). When this occurs something more needs to be known about the reference plane (such as does it have a steep or a shallow dip)? In some situations, the two answers can become close enough that it is impossible to choose the correct solution. For this reason, care must be taken to examine such ambiguous solutions when using software to perform the calculations. Our package, GeoCalculator, will produce the 'best-fit' solution as the primary solution, but then set out the ambiguous alternatives for the reference plane solution, which you need to check manually.



USING GEOCALCULATOR TO PROCESS DRILLCORE DATA

(GeoCalculator can be downloaded from: https://www.holcombe.net.au/software/)



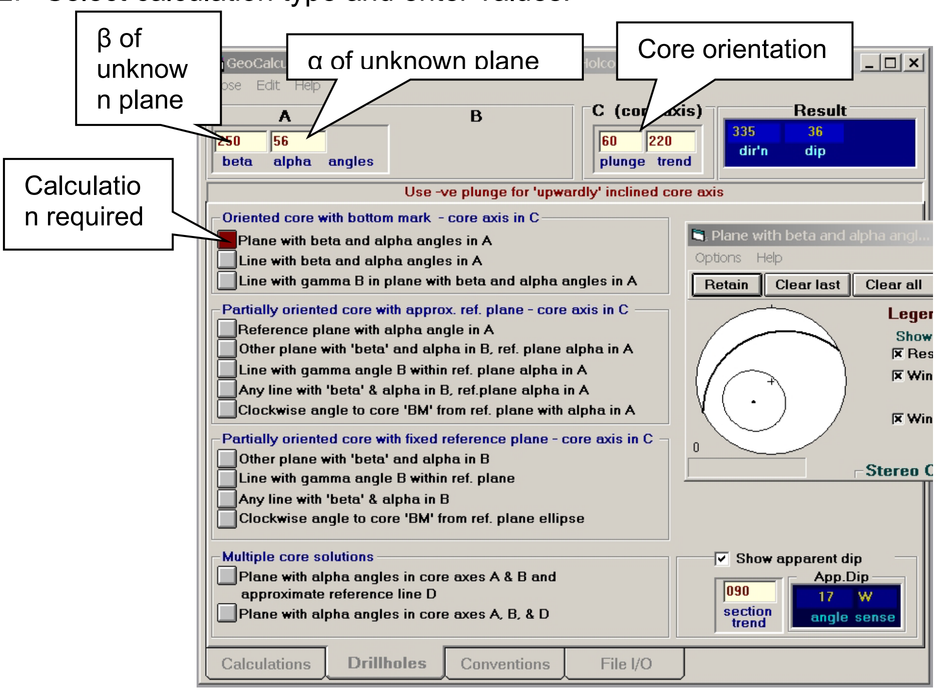
1. Set the measurement conventions:

* **Plunge** is the correct term for the angle of inclination of a line such as a drillhole. The term **dip** to refer to the plunge angle has become entrenched in the mining industry (because of careless usage by some of the early orientation software packages).

** **Zenith** is the complement of the plunge. It is the angle of the hole from the vertical. It is an unusual convention used by some inclinometer manufacturers.

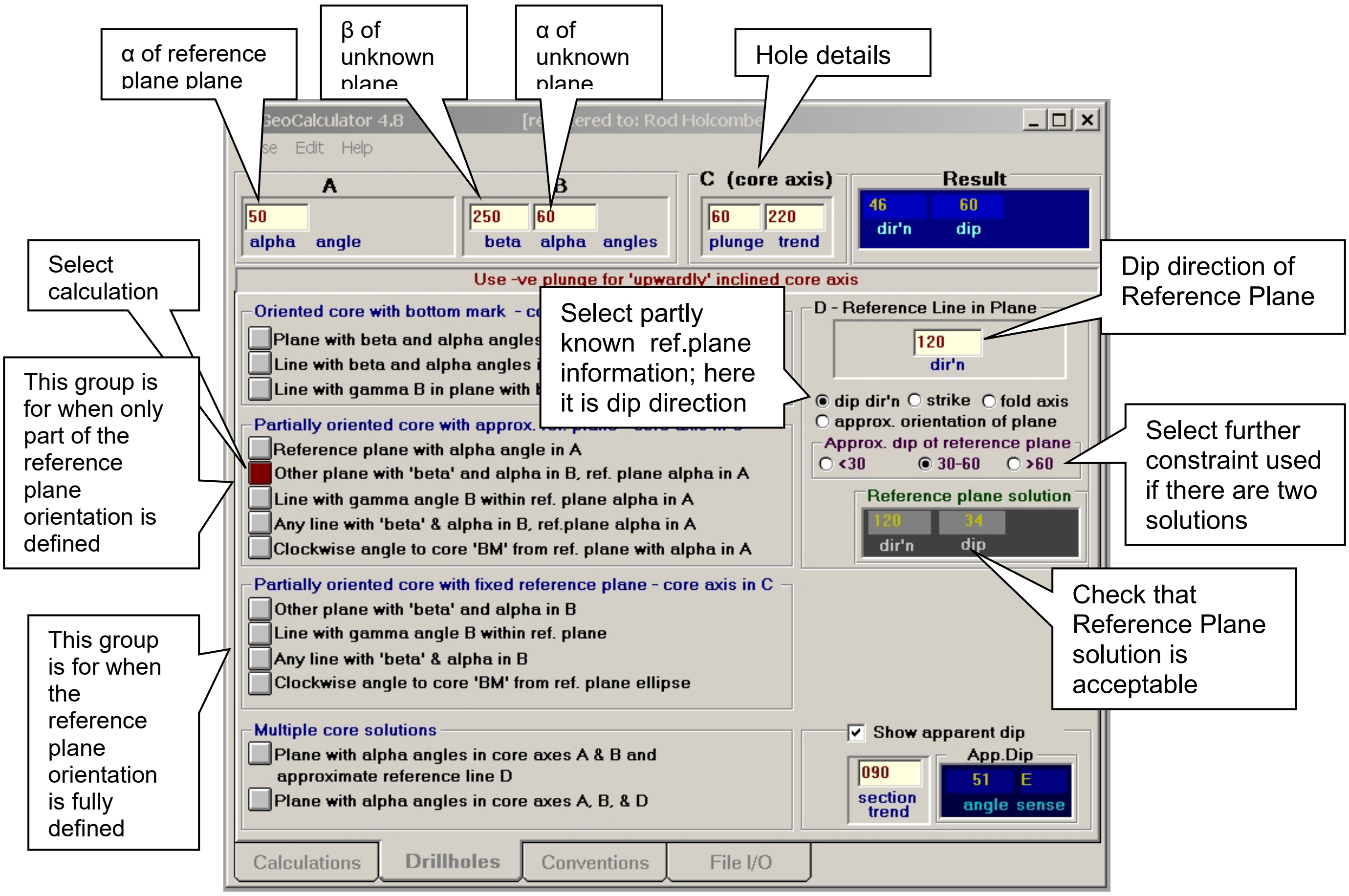
Using GeoCalculator with Oriented core

2. Select calculation type and enter values:

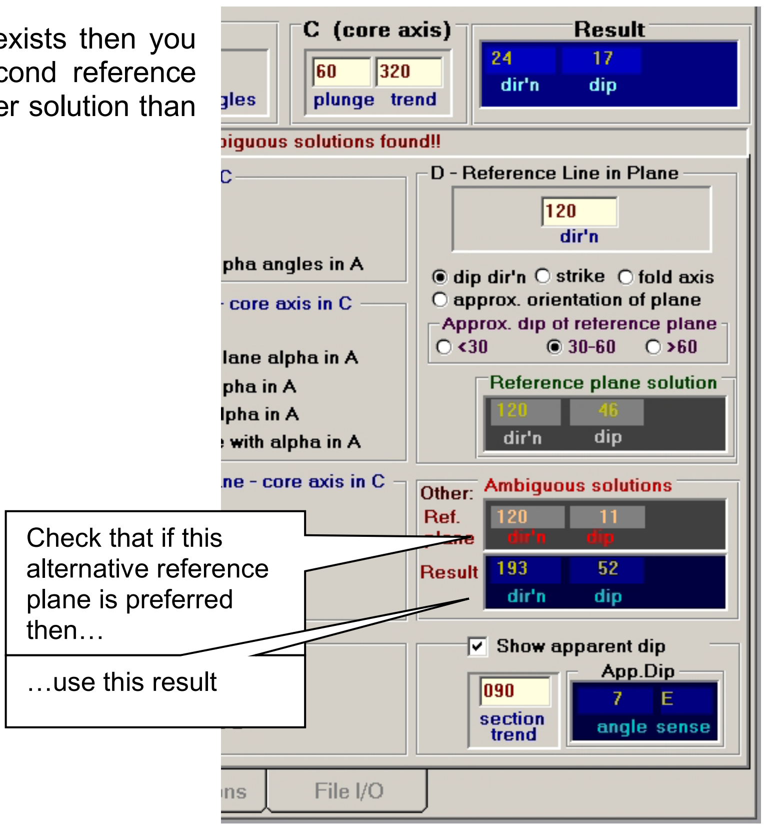


Using GeoCalculator with Partially-Oriented core

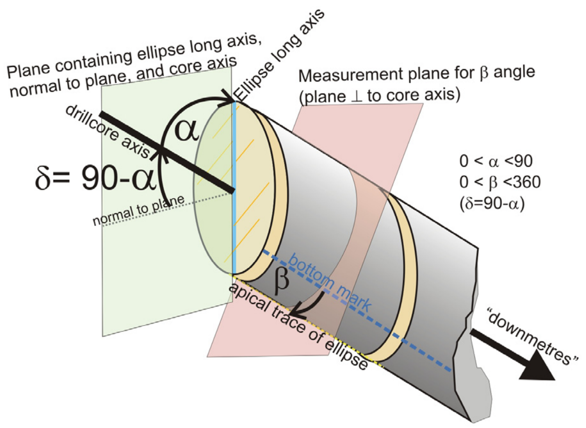
Example: Calculating the orientation of an unknown plane given the dip direction of a known reference fabric plane and its alpha angle in the core:



If a second ambiguous solution exists then you may need to check that the second reference plane might not have been a better solution than the one chosen.



MANUAL STEREOGRAPHIC PLOTTING OF ORIENTED CORE



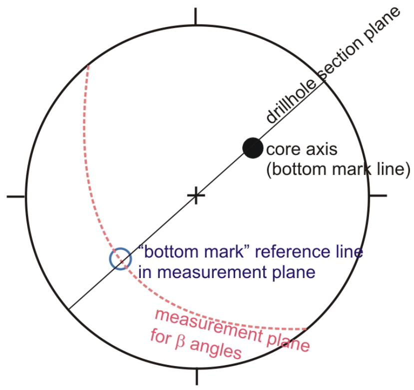
The conventions assumed for the following description are:

- Alpha – acute angle between core axis and ellipse long axis
- Beta – angle clockwise from 'bottom mark' to **bottom** of ellipse (looking 'downmetres').

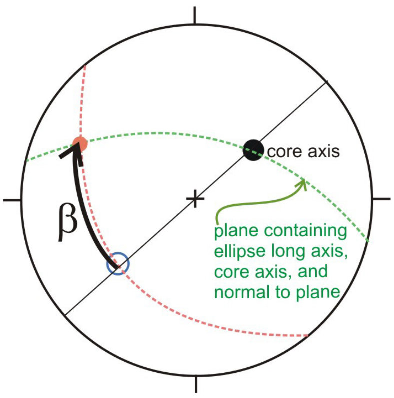
The diagram and description on this page applies specifically to a plane with a small (<90°) beta angle. See the following page for how to handle large beta angles.

Procedures

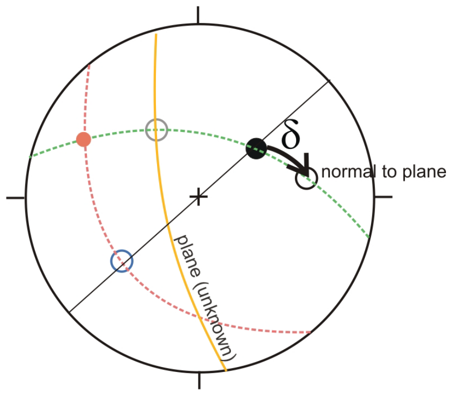
Step 1: Plot the core axis (parallel to the bottom mark). This axis is the pole (normal) to the measurement plane great circle. Draw the measurement plane great circle and mark its dip line. This is the bottom mark reference line for measuring the beta angle. (This assumes that the convention used is to mark the bottom of the core, not the top)



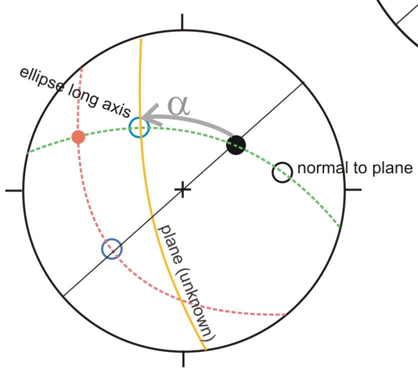
Step 2: Count the beta angle along the measurement plane great circle, clockwise from the 'bottom mark' reference line. Draw a great circle through this point and the core axis. This great circle (ellipse-core axis great circle) is the plane that contains the normal to the ellipse (the unknown plane we are trying to find).
(Be careful here to preserve the sense of direction of the beta angle line – see next page)



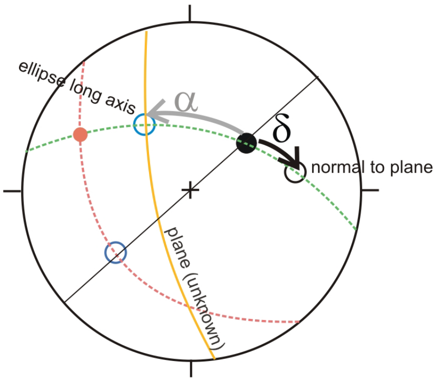
Step 3: Calculate the delta angle (90-α). Using the rules developed on the next page, find the **normal** to the ellipse (the unknown plane) by counting the delta angle along the ellipse-core axis great circle. (Use the rules developed on the next page to determine whether to count the delta angle away from, or toward, the beta line).
Plot the unknown plane. (The normal is the pole to this plane).

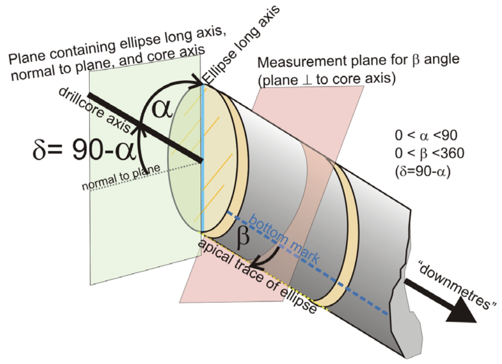


Note that we have not used the alpha angle directly. Although we can find the ellipse long axis using the alpha angle – this is not sufficient to determine the unique solution for the plane.



Details of step 2 and 3: preservation of sense of beta direction and sense of counting of delta angle

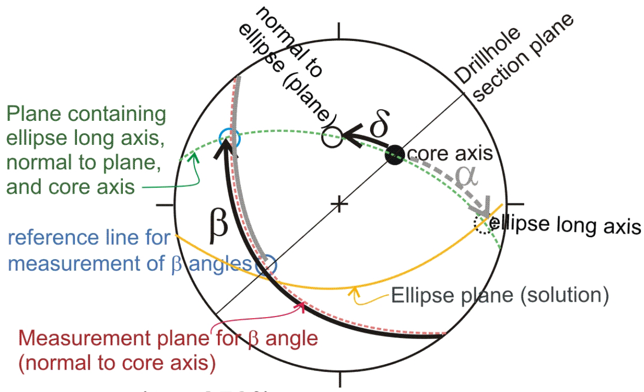




In our assumed conventions, the beta angle references the angle to the bottom of the ellipse long axis in the core. Care must be taken when finding this beta line in the measurement plane to remember whether it plunges downwards or upwards in the measurement plane, as this affects the sense in which the delta angle is counted.

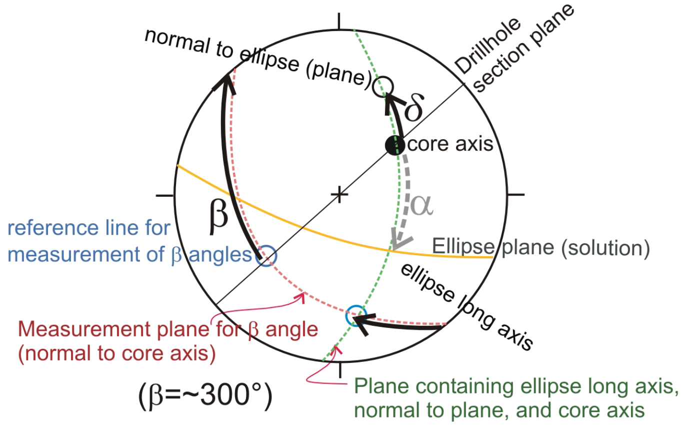
In the calculation described on the previous page, the beta angle is less than 90 (~70), so the sense of plunge of the beta line is downwards (to the NW in the stereo) so we plot it with a filled circle. This means that the long axis of the ellipse must also plunge toward the same quadrant. Hence the delta angle to find the normal is counted from the core axis **away** from the beta line in order to find the normal.

Now consider the case of a beta angle >90 and <270 (the example shown is ~250):
In this instance the point representing the beta line is in the same location in the stereo as our β=70 example. That is, it still plunges to the NW, but its sense is upward in the measurement plane (so we plot it with an open circle). What this means is that the ellipse long axis is plunging away from the bottom mark, hence the normal will be found by counting the delta angle from the core axis **toward** the beta line.



(β=~250°)

The 'rule' for a beta angle >270 is the same as for the <90 case (e.g. the figure shows a beta angle of ~300). That is, the delta angle is counted from the core axis **away** from the beta line



(β=~300°)

Put simply the 'rule' is:

- for beta angles from between 90 and 270 measure the delta angle from the core axis **toward** the calculated beta intersection line in the measurement plane;
- for all other beta angles measure the delta angle from the core axis **away** from the calculated beta intersection line in the measurement plane.

OTHER CALCULATIONS

Interpolation of drillhole surveys

Oriented core calculations require knowing the orientation of the drillhole at the point that the observations are made. The drillhole orientation used might be an approximation based on the nearest hole survey or, if greater precision is required, then the core orientation can be interpolated between surveys to the observation depth. Modern exploration software (Micromine, Datamine, etc) will do these calculations on the fly and may use quite sophisticated algorithms to do so. However, there is a simple procedure that can be carried out in a spreadsheet (although it is best done by defining a set of macros to do it).

The following is a numeric, not a geometric, solution and assumes that there is a uniform change of orientation between drillholes. That is, that the plunge angle changes linearly between successive surveys, and the azimuth changes linearly. The assumption is reasonable, provided that the distance between surveys is not too large.

The algorithm is to calculate the fractional distance of an intermediate structural reading between the depth of the survey above and the depth of the survey below. Let us say that the upper survey is at 200m, your reading is at 220m, and the next survey is at 250m. Then your reading depth is 20/50 of the distance (i.e. 0.4).
Now use that same proportion to interpolate both the plunge angle difference between the surveys and the azimuth difference. So if an upper survey at 200m was 68/351 (plunge/azimuth) and a lower survey at 250m was 65/356, then the drillhole plunge at 220m will be 68+(0.4x(65-68)) = 66.8.
Similarly, the hole azimuth will be 351+(0.4x(356-351) = 352.6

(Any macro has to check and correct for azimuths >360, azimuth-flips when the hole passes through the vertical, and to allow for the use of inclinations with downward -ve values).

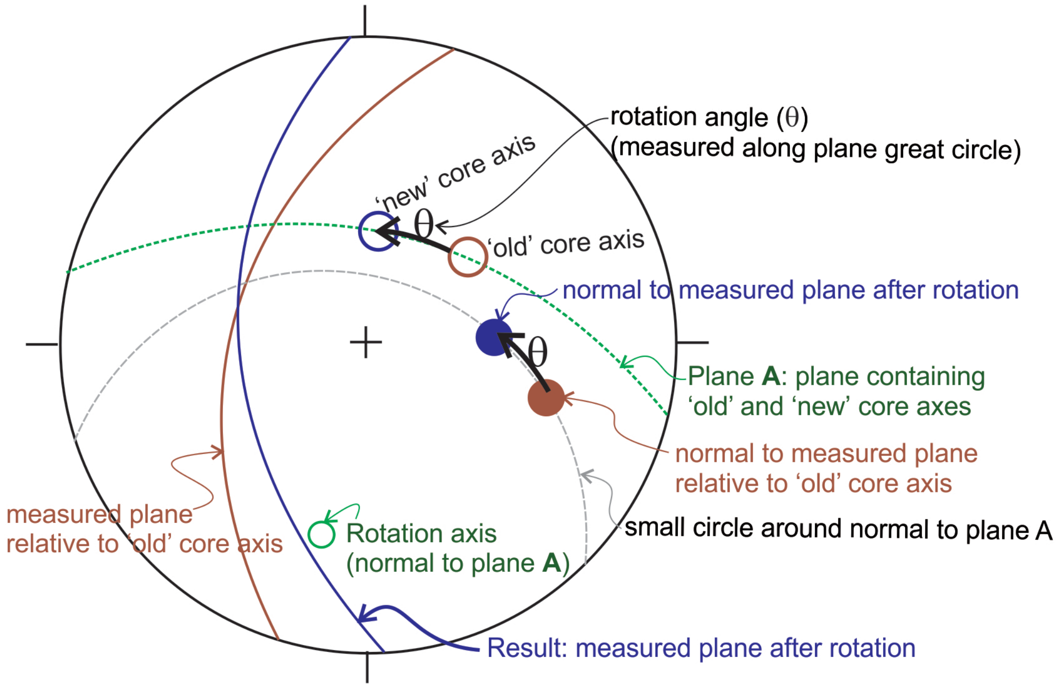
Correcting structural data for subsequent changes in hole surveys

From time-to-time oriented core data are calculated based only the collar orientation of the hole. For example, core structures for an entire hole might be measured using a ‘rocket launcher’ jig without changing the orientation of the jig between measurements. If subsequently the hole is surveyed such that the precise core orientation is now known for each measured orientation, can the original data be corrected? The answer is yes; but it is a little tedious and you need to understand how to rotate planes and lines in 3D space. Essentially, we need to rotate all of our data around the same axis, and by the same angle, as the apparent rotation between the ‘old’ presumed core axis and the ‘new’ true core axis. Unless the ‘old’ and ‘new’ core axes lie entirely within a vertical plane orientation, It is not enough to rotate either just the dip angle, or just the strike angle, by a fixed amount. The rotation will change both dip and strike.

The following figure (next page) shows the rotation geometry in stereoplot space. The things to remember are that:

- the axis of rotation is normal to the plane containing the old and new core axis orientations, and the angle of rotation is the angle between the old and new core axis;
- in stereoplot terms, the axis of rotation is the normal to the plane containing the points representing the old and new core axis orientations; the angle of rotation is measured in this same plane and is the angle between the old and new points;
- all lines are rotated around this rotation axis by this same angle and in the same sense;
- lines that rotate around an axis, trace out the surface of a cone; in stereoplot terms the path traced out by a line (point) is a small circle around the rotation axis;

- for planes, it is the rotation of the normal that is calculated. The dip and dip direction (etc) of the new orientation of the plane can be recalculated from the new orientation of the normal.



It is tedious to have to go through this manual plotting process for each structural measurement. The process can be done a little faster (and for large batches) using structural calculation applications (such as GeoCalculator, described earlier). But even then, the process requires multiple steps. For example, in GeoCalculator the sequential steps required are:

1. Determine the plane (**A**) containing the 'old' and 'new' core axes
2. Determine the normal to this plane
3. Determine the angle (θ) between the 'old' and 'new' core axes, preserving the sense of rotation from 'old' to 'new'. (That is the sense of rotation looking down the normal onto plane A).

At this point we have the information to rotate any of our data into this 'new' orienation

4. Rotate any data planes (or lines) around the axis determined in 2, by the amount determined in 3 (ensuring that the sense of rotation observed in 3 is preserved).

Applications like GeoCalculator handle the background complications associated with the rotation, but you still have to monitor the process. For batch processing, the results from calculations 2 &3 could be combined in a spreadsheet with the raw data to be transformed, and then run step 4*. Clearly it would have been better to have processed the core structural observations right from the start with the correct core orientation.

[*It is my intention to add some future calculation options to GeoCalculator to streamline this process]

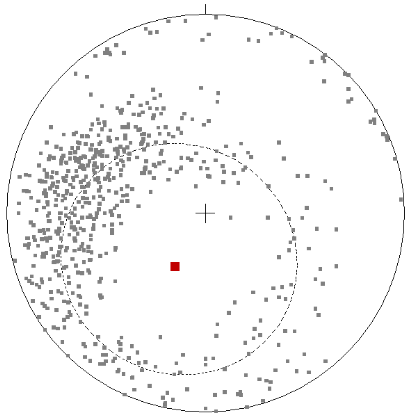
QA/QC: ERROR DETECTION AND CONTROL

Structural measurements derived from oriented drillcore have a range of potential error sources that must be continually monitored and minimised in any large-scale, long-term drilling program.

Errors can occur at several stages in the orientation and measurement process:

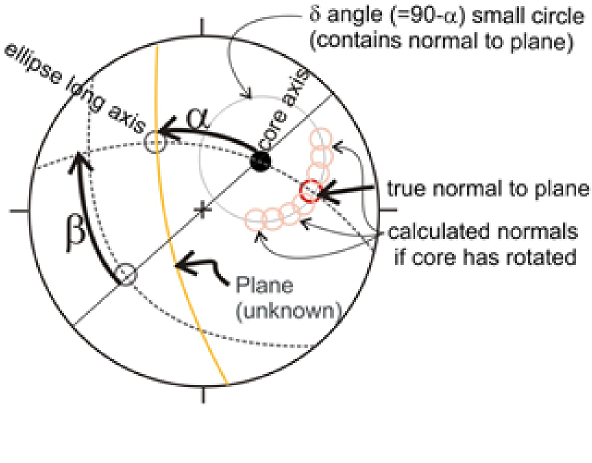
1. The orientation mark might be imprecise or incorrect. This is a problem with the driller's technique and expertise. For example with a 'spear' tool the tip of the tool should just touch the top of the core run and be lowered slowly, so as not to bounce the spear off the bottom of the hole. The on-site geologists need to monitor the orientation process and impress on the driller the need for precision.
   Many modern digital downhole orientation tools (such as those produced by Imdex/Reflex) can have very high precision. Nonetheless, they are still susceptible to user error (and that user is commonly a driller's offsider with no vested interest in the result). I routinely find examples of misoriented core recorded using these high-end instruments. It is not prudent to assume that just because the instrument has high precision (and you have paid a premium), the results are therefore highly accurate.
2. The orientation mark may be translated imprecisely onto the core by the logging geologist or technician. Core sections in broken core may be inaccurately aligned when aligning the bottom mark along the core. The bottom mark line may be accidently marked along the top of the core, or the down-hole arrows might be drawn the wrong way.
3. Errors can arise from imprecise identification of the ellipse long axis or with the alpha and beta angle measurements.
4. Statistical errors can arise from bias in the choice of which features to measure, or even from drillholes that are inappropriately oriented relative to the feature of interest.

The most common source of error in structural data from oriented core, is in the location of the bottom line (either at the drilling site or during the mark-up stage), but recently I have seen an example where a poorly motivated junior geologist had entered random beta angle numbers in a lazy effort to get his 'quota' of measurements completed.



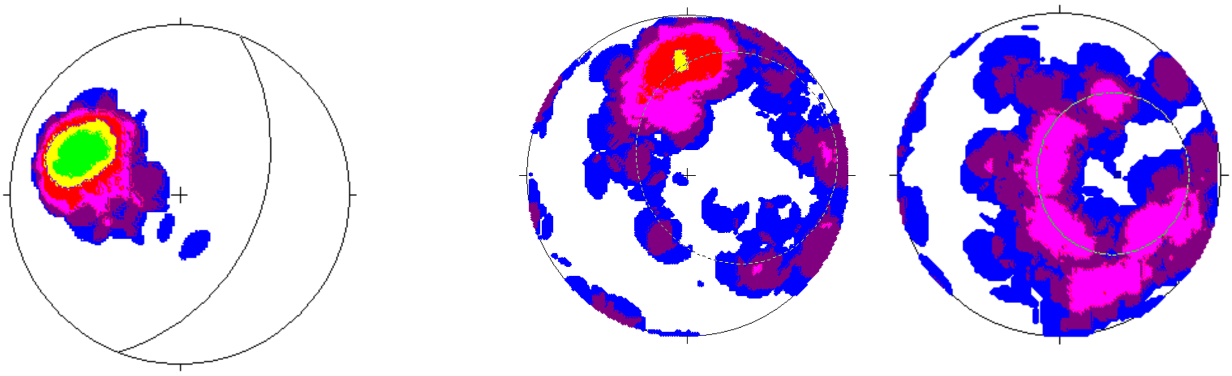
Errors should be suspected if stereographic projections of poles to planes show small circle distributions centred on the drill-hole orientation. This most commonly occurs when the hole intersects a moderately uniformly dipping feature (e.g., bedding, foliation, or sheeted veins) but the core has undergone some degree of random rotation ('spin') during the measurement or marking of the orientation lines (see lower figure for explanation). The same small circle effect can also be produced at the measurement stage if there are systematic random errors in the measurement of the beta axis.

(Note that small circle distributions can occur naturally, but the type of structures that produce them (conical structures) are uncommon and should show no relationship to the orientation of the drillhole).



***Top**: Example of poorly oriented data from multiple drillholes, showing a small circle distribution around the common drillhole orientation (core axis (red square). N=627*
***Bottom**: Stereographic construction showing small circle path of all possible normal to a plane with a fixed alpha angle.*

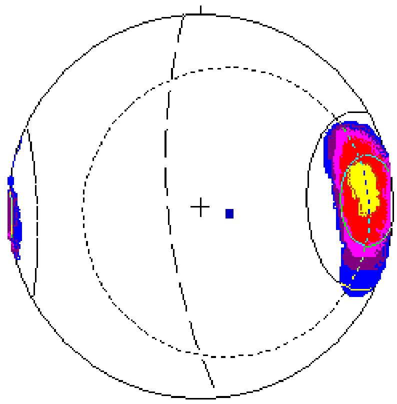
The left hand plot below shows 102 cleavage data obtained from well-oriented core. The cleavage in this area is known to be relatively constant and the stereographic projection shows the expected unimodal maximum, and a slight great circle that reflects fanning of the cleavage. The core is drilled at ~70°W and there is no element of apparent rotation around this orientation. (Data from multiple adjacent cores are included in the plot). The two plots to its right are from data collected in drillholes oriented 60° east in a single project. Both show small circle distributions around the core axis. In the rightmost plot the data are uniformly distributed around the core axis orientation, indicating relatively random rotation of the core relative to the orientation mark. All of these data should be discarded. The other plot contains a strong maximum, which probably reflects the true orientation of the measured plane, but the rest of the data need to be discarded. The appearance of any small circle distributions at all is an indication that current orientation procedures may be flawed, and all orientation data are suspect until the cause is found and eliminated.



It is worth monitoring any known constant planar feature (such as a weak crenulation) in the drilled rock simply as a check on the reliability of core orientations. For this type of QA/QC monitoring to be successful it is imperative that sufficient measurement data be collected. This is not commonly done in a single drill-hole (although it becomes critical to do so in folded areas). A good practice would be to take at least two measurements on the constant fabric (e.g. cleavage) within each run of oriented core. Then not only can the precise modal orientation of the fabric be determined, but the relative 'spin' of each run can be monitored and adjusted if necessary. The temptation is for the geologist to under-measure such 'constant' fabrics because its orientation is presumed to be well-known and thus not 'important' to measure.

What is well-oriented core?

The data plot shown in the left hand image at the bottom of the previous page is unusual; almost all structural data from oriented core shows an element of 'spin' that manifests itself as a 'smiley face' in unimodal data. What you want to see is the 'smile' spread being as small as possible. As the use of oriented core becomes more widespread, explorers are tending to move away from the fast cheap methods (e.g. the 'spear') toward more technologically advanced methods with supposedly higher precision. However, despite the higher theoretical precision, data obtained using these instruments still tend to show considerable elements of spin. The plot at right is quite typical of data I am shown from what is considered to be well-oriented core. Yet a closer look shows that although the mode is well defined, individual data points have spun up to ±30° from this mode. Thus for statistical use the data is quite accurate, but individual readings,



Plot of cleavage data in core that is considered to be reasonably well-oriented (oriented using a Reflex ACT tool). The plot shows a small circle distribution around the drillhole orientation (blue square) over an arc of about 60° (producing the 'smiley face'). The large small circle shows the expected path of data that has 'spun' around the core axis. The two smaller small circles enclose spreads of 30° and 60° respectively.

plotted for example as apparent dips on drill sections, have a precision of only ±30°.

It is worthwhile to consider what might be the best precision we can expect. The apparent rotation ('spin') can occur:

1. at the drilling stages from inaccuracies in the orientation tool or the initial marking process;
2. at the bottom line mark-up stage by incorrect docking of broken core or inaccurate projection of the line along the core;
3. at the measurement stage by the geologist from imprecision or inaccuracies in identifying the bottom of the elliptical trace of surfaces on the core, or in measuring the beta angle.

In 63.5mm diameter (HQ) core, 10° of 'spin' equates to 5.54mm around the circumference of the core and errors arise from this linear measurement. Tool suppliers of modern instruments do not quote precise tool measurement precision, except to say 'highly accurate' in their sales pitch. It might be presumed that 'highly accurate' should be an accuracy of ±3mm in locating the bottom mark on the core circumference, which corresponds to a precision of about ±5.5°. At the mark-up stage, where the bottom mark is projected along the core as a line, the error should no more than ±1mm, which corresponds to ~±1.8°. (This is the easiest stage to have full control on precision – and it should be exercised). Most beta angles should be measured to the nearest degree, although the effective error in the combined measurement precision and the accuracy of identifying the base of the ellipse is commonly ~±5° for HQ core (±2.8mm).

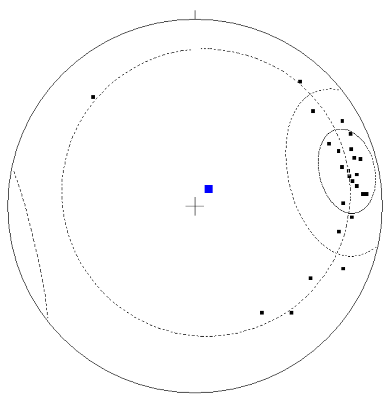
Thus, even in the very best oriented core, there is an expected degree of uncertainty in HQ core of about ±12° in the final beta angle. (Because of the difference in circumferences, the maximum precision of NQ core will be ~±16°, and ~±9° for PQ core).

It can be seen that the largest source of error may very well be at the beta measurement stage, and geologists need to be made aware of the need for maximum precision at this stage. The precision will be considerably worse if beta angles are only measured to the nearest 10°, a practice that is not desirable, but is not unusual.

Areas that have a reasonably constant fabric, such as a cleavage, can use that fabric to both calibrate the orientation precision of the core and to identify which intervals have 'spun' provided that sufficient measurements on that constant fabric are done. In general, try and obtain at least two measurements in each run of oriented core.

Quality control: A core orientation rating for an entire drillhole

Using ±15° as being the precision of near-best-practice, and recognising that ±30° is quite common, the following describes a possible way to use such a constant fabric to quantify the orientation precision based on an analysis of the stereographic distribution of poles to the constant fabric:



1. Identify the location of the modal orientation (the centre of the maximum density). Record the total number of data points in column C in the table shown on the next page.
2. Plot the mean core axis on the plot (blue square in image right)
3. Plot a small circle centred on the core axis and passing through the modal orientation.
4. Plot two other small circles, centred on the modal orientation and with half-opening angles of 15° and 30° respectively.
5. Count the number of points between the two smaller small circles. That is, data that lies 15-30° from the mode. (4 points in the plot). Enter into column D in the table below.

6. Count the number of points that lie outside the 30° small circle. (6 points in the plot shown). Enter into column E in the table below).

The following uses spreadsheet calculations to determine the number of modal data within the inner small circle (column F); to produce a weighted total of the spun data (column G); and to calculate the resultant ratio of spun to modal data as a percentage. (column H). Here I have given the near-modal data half the weight of the fully spun data. Column I is a Hole Orientation Rating. It is simply a reworking of H as a score out of 10, with 10 being 100% modal.

The data shown in the stereographic projection on the previous page is in the first row of this table, with a resultant Rating of 5. Although mode precision for the data shown is fairly good, the orientations of individual data points are moderately unreliable. Both mode precision and individual precision become unreliable with ratings less than 5. Note that these ratings need to be tempered by a consideration of the total number of data. In drillhole 010 for example, there are only 5 data, yet the Ori Rating is 10. Clearly there are not enough data to properly characterise the orientation precision in that core.
Note that this rating characterises the entire hole, not individual runs within the hole. Although it could be used as a general check on how well core is being oriented from hole to hole at the drilling sites, that conclusion needs to be tempered by the fact that part of the precision error potentially occurs at the later technical stages. So it is really a check, per hole, on the entire process of obtaining orientation data, not just one part of the process.

Cleavage										
A	B	C	D	E	F	G	H	I		
Hole_ID	**Mean Core axis**	**Total data N**	**Near-modal data 15-30°**	**Number data >30°**	**Num Modal data (<15°)**	**Weighted Spun data E+(D/2)**	**Weighted spun data to modal data G/F %**	**Hole ORI rating (100-S)/10**	**Mode definition**	**Individual Precision**
001	81-038	25	4	6	15	8.0	53	5	Fair	Moderately unreliable
002	80-100	44	12	3	29	9.0	31	7	Good	Acceptable with care
003	77-103	35	6	2	27	5.0	19	8	Very Good	Moderately reliable
004	76-101	16	4	2	10	4.0	40	6	Good	Unreliable; sparse data
005	73-101	37	6	0	31	3.0	10	9	Very Good	Very reliable
006	75-114	49	9	2	38	6.5	17	8	Very Good	Moderately reliable
007	77-109	38	6	2	30	5.0	17	8	Very Good	Moderately reliable
008	77-088	29	10	2	17	7.0	41	6	Good	Moderately unreliable
009	86-092	33	5	3	25	5.5	22	8	Very Good	Moderately reliable
010	80-090	5	0	0	5	0.0	0	10	Good	low data; poorly characterised
011	80-037	17	3	3	11	4.5	41	6	Fair	Unreliable; sparse data
012	71-139	31	5	2	24	4.5	19	8	Very Good	Moderately reliable
013	36-265	19	2	2	15	3.0	20	8	Very Good	Reliable, but sparse data

Sources of error and minimisation of error

Of all of the available core orientation systems available on the market, the simplest, cheapest, fastest, and most commonly used is the ‘spear’. The orientation spear is a long conical rod tipped with a hole for holding a sharpened crayon pencil. It only works on inclined holes. The tool is lowered down the core barrel until it makes a mark on the start of the next section of rock to be drilled. Because of the inclination of the hole the rod lies along the bottom of the barrel and the crayon marks a spot that ideally is close to the lowermost line of the core.

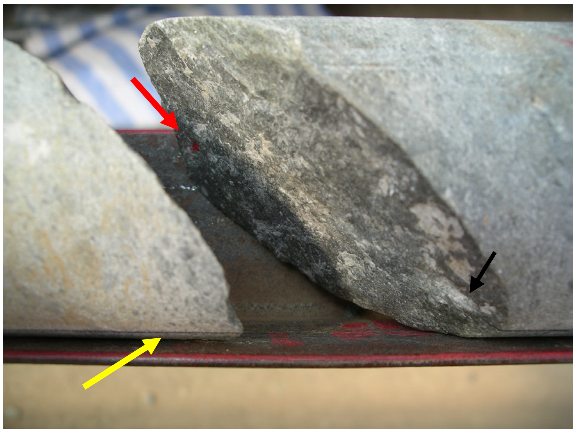
Note that the smaller the core size, the greater is the potential for error. Because the thickness of the spear rod approaches that of the core, NQ core is particularly prone to producing an orientation mark that is too close to the centre of the core to define an accurate ‘bottom’ line.

Potential errors at the drilling stage:

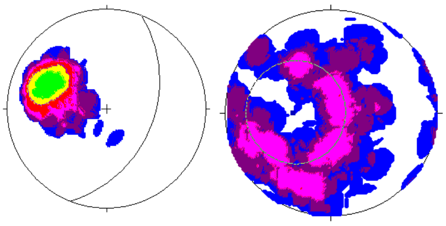
- Bending or distortion of the spear rod. Both the supervising geologist and the driller should inspect the spear rod before any new drill hole. Roll the rod on a flat surface to detect distortion.
- Dropping the spear too fast onto the rock, such that the spear either bounces off the wall of the core barrel or impacts too fast onto the rock and produces several impact marks. Ideally the spear should just touch the rock and then be withdrawn. There should be no impact marks at all. (For example, the top photo right shows the crayon spot from a hole in which orientations were taken every 10 metres. None of the orientation marks in that core show any sign of impact of the spear apart from the crayon mark, a reflection of the drillers care.

The photos at right are examples where the spear has dropped so fast that it has impacted, broken the crayon and then bounced making other impact and chatter marks. In some instances, such as the photo at far right, the impact is enough to cause chatter marks across the entire core face, or to even chip the edge of the core and destroy the crayon mark.

- Manually inserted orientation marks. Although it is clearly poor drilling practice, occasionally evidence arises that an orientation mark has been manually inserted. For example, the orientation spot in the core at right is shown by the red arrow. There is clearly a spear impact feature (with no crayon mark) on the opposite side of the core (black arrow). When this core was realigned with adjacent runs it was found that the impact mark, rather than the crayon mark) lined up with the bottom line (yellow arrow) projected from the adjacent core runs. In this instance, the core was produced during a night shift and it is likely that the impact mark was not seen by the person marking the crayon manually. Most long-term geologists have experienced similar stories.

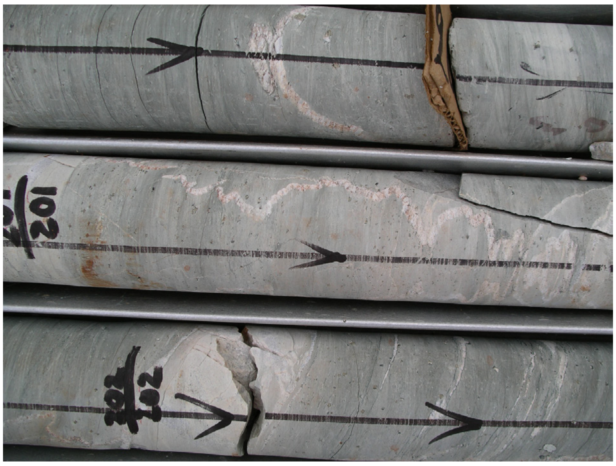


One possible way around expensive geological vandalism of this sort is to involve the drillers directly into the geologist's world by showing them the end results of poor drilling. I have done this at the start of one drilling program by showing the drillers photographs of some of the good and bad crayon orientation marks shown above and then showing them examples of the stereographic plots of good and bad results (without, of course, going into the detail of what these plots are). I just showed them a bulls-eye from good data versus the small-circle patterns for poor data, with the comment that we should never see such circles.

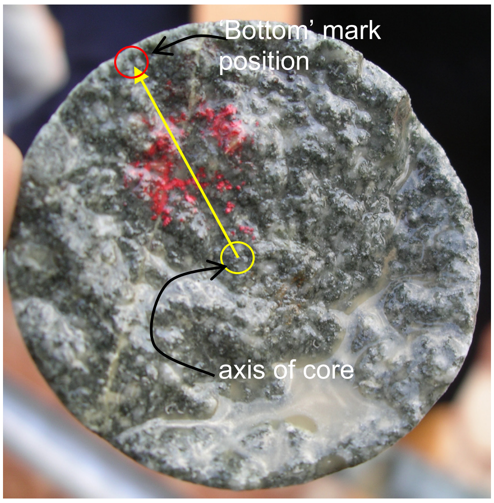


Drilling contracts should contain penalty clauses for unsatisfactory orientations above an acceptable level. Most such errors are produced by drillers trying to minimise the downtime required for the orientation procedures. Rather than rush the procedure and make costly geological errors it is better if the drilling contract properly accounts for the time required.

Potential errors at the mark-up stage:



Once core with an orientation mark (spot) has been extracted, the next step is to draw a line marking the bottom of the core. This line is generally marked with arrows showing the down-hole sense, and preferably should be in a different colour to that used to mark the cutting line of the core. (Note that the when core is split for assay, the orientation line should always be on the half that is left in the box). The lines extend as far along the core as it is possible to match broken core segments up. At least one down-hole arrow should occur on every segment of the core. If the core cannot be oriented then do not record an orientation line. No information is better than wrong information.



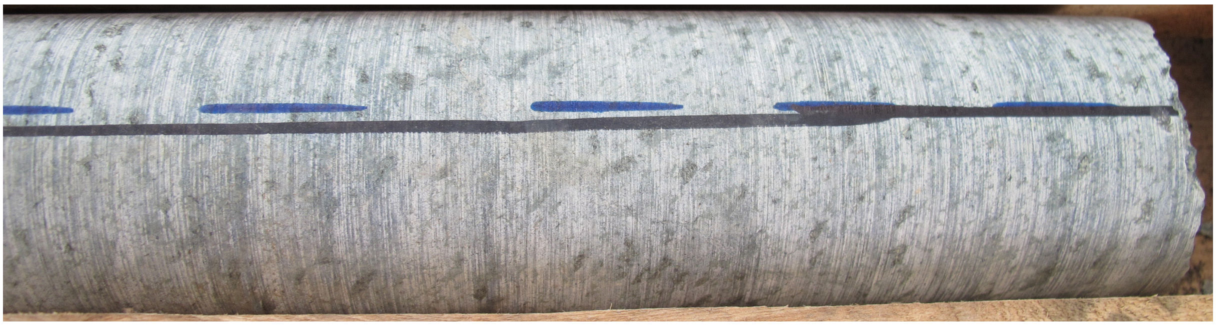
Errors arise with the matching of the line across broken core segments. Note that it is very easy at this stage for small rotation errors to creep in and these affect the accuracy of the beta angle measurements. For this reason it is best if this part of the process is done under very controlled conditions. The core is laid out on a rack of sufficient length to hold at least three or four complete runs of core. Not only should the bottom line be extrapolated along each run of core, it should also, where possible, be matched with the adjacent runs.

***Top**: Orientation bottom-of-hole (BOH) line on oriented core. The cutting line has not yet been marked on this core but should be done with a differently colour.*
***Middle**: Procedure for finding the BOH line with a spear.*
***Bottom**: Misoriented BOH line (solid) across a break in the core. The cutting line is dashed here, but would be better with a solid line of a different colour.*

The best core racks are made of rigid angle-iron. The core is then lined up with the bottom line lying along this edge of the angle-iron, which forms a solid straight edge for drawing in the line. Be careful that the angle iron is thick enough not to warp, and check its straightness periodically. Other racks are made using lengths of drill rod welded together, but these do not provide the useful straight-edge of the angle-iron. Least desirable (and unfortunately most common) is to draw the orientation line directly on the core in the core box.

***Top right**: Angle iron rack for marking BOH lines*
***Bottom right**: BOH rack made from clamped or welded drill rods*
***Above**: Adjacent core runs matched together in angle iron. The red spot marking the top of the lower run can be seen at the top of the core run to the right. Note the good straight-edge provided by the edge of the angle-iron.*
***Below**: BOH line (solid black) oblique to the core axis (which is parallel to the blue cutting line). The error across this image is about 12°. The BOH line was drawn with a metre rule. The junction between two rule marks (with slightly different orientation can be seen (arrow).*

Errors can also arise if the straight edge used to mark the line is too short. In these instances it becomes too easy to accidently draw the line slightly obliquely to the core axis.



The driller's involvement with core orientation should end with the identification of the bottom mark. It is poor practice to allow the driller to mark-up the core as this will generally be done by the driller's offsider, and neither may have a vested interest in the accuracy of the mark, or knowledge of how important it is for precision.

The errors involved from misorientation of the bottom line are easy to calculate. 10° of error is equal to the circumference of the core divided by 36. For example, in HQ core, with a circumference of about 200mm, 5.5mm of offset is a 10 degree error. An error of more than about 20° (11mm) becomes too inaccurate to be useful. The three images at right show just a few of the multiple errors in the orientation line (black) drawn on core from a small interval of a single drillhole. The degree of mark-up error (up to 60°) means that none of the measured structural data from such core can be used with any confidence.

Examples of incorrectly drawn BOH line (black) by a driller's offsider in a single short interval of core.

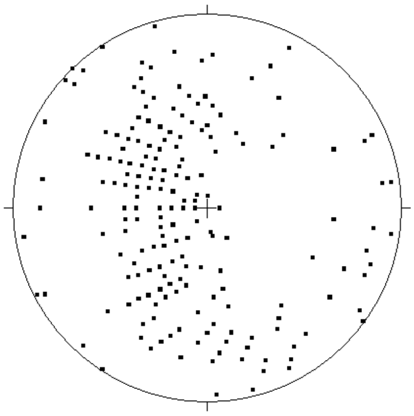
The examples shown are from a project where the driller's offsider was instructed by the project senior geologist to mark up the BOH line along the core at the drill site. He did so with a short metre rule, and at times under poor lighting and weather conditions. The resulting errors are costly, but should not have been unexpected. The errors here were never picked up, because the structural data measured was never used! The senior management off-site had mandated core orientation, but had not properly instructed the people on-site why they were doing it. For them, orienting and measuring core was just another routine chore being done for someone else!

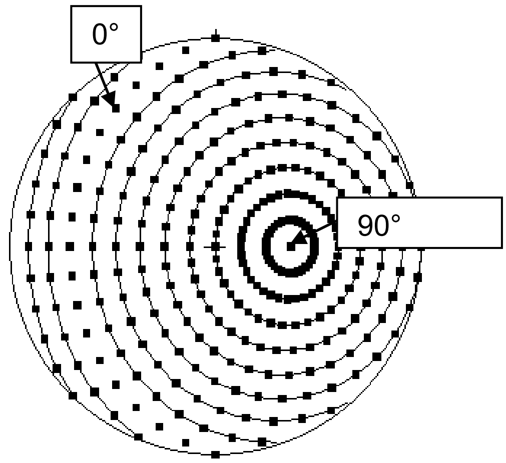
Other errors at the core mark-up stage that I have seen include: accidently marking the BOH line along the top of the core; incorrectly marking the downhole arrows; and having a section of core that has been inverted when replacing it back into the core box at some point prior to the mark up.

Potential errors at the measurement stage

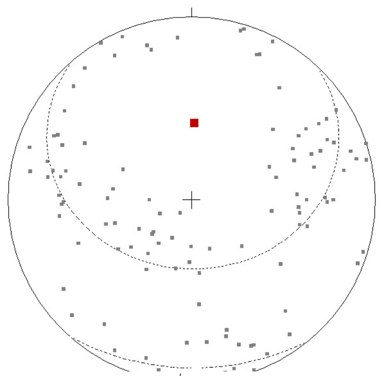
Errors at the measurement stage arise from measurement imprecision and from accidently using the wrong measurement conventions, particularly of the beta angle. Examples of the latter that I have seen include measuring the beta angle to the wrong end of the ellipse, accidently measuring anticlockwise (sometimes caused by reversing the measurement protractor).

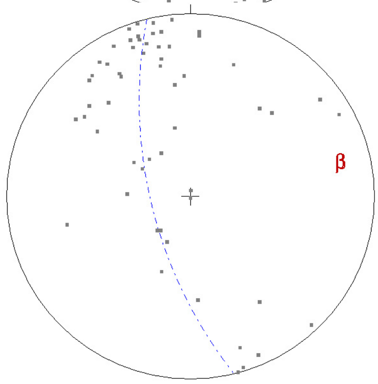
- **Errors of precision.**
  Errors due to measurement imprecision are avoidable by doing all angular measurements to a precision of 1° (even though the measurement process may have an accuracy >1°). It is very poor practice in any circumstance to round off geological angles and directions to the nearest 5 or 10 degrees. The result is that such data produces a 'starfish' pattern on stereographic projections (figure, **right**) and these patterns distort contouring procedures and mask local density accumulations.
  The effects on precision of rounding alpha and beta angles to the nearest 5° or 10° depends on the alpha angle. The plot at right shows poles to planes with alpha angle varying from 0 to 90° (the small circles), and for each alpha angle the beta angles range from 0 to 360. The plot shows that an error in alpha angle gives the same error in the result, but that an error in the beta angle produces an error in the result that is **smaller** than that in the beta angle. (For true alpha angles of 0, the error is the same as the error in beta; for alpha angles of 90 the error reduces to zero. (This result reflects the fact that where a plane is perpendicular to the core, the beta angle is irrelevant).





- **Errors of measurement** are unavoidable and largely undetectable unless the data interval is remeasured.
  The top example at right is from an interval in a single drillhole where the geologist's log showed a large number of measurements of bedding that had been identified as 'foliation'. It shows the typical small circle distribution of poorly oriented core, but as this interval was well-bedded pebbly sandstone, and largely devoid of foliation, I remeasured it. The results are shown in the bottom right image, and show a great circle (indicating folding) but little evidence of a small circle distribution that might indicate poorly oriented core. Nor did the data distribution resemble anything in the first plot. In this instance, the small circle distribution resulted from the geologist recording random beta angle numbers. (By the time I examined this core, he had already been sacked for other shoddy work).

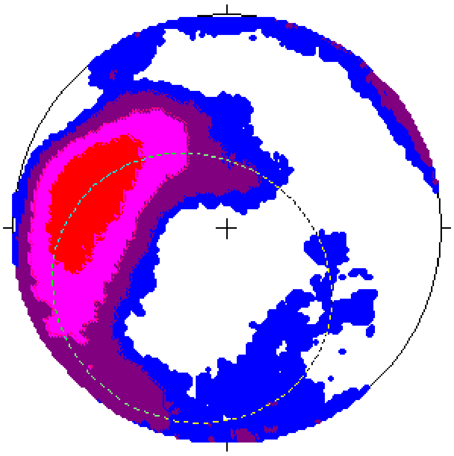


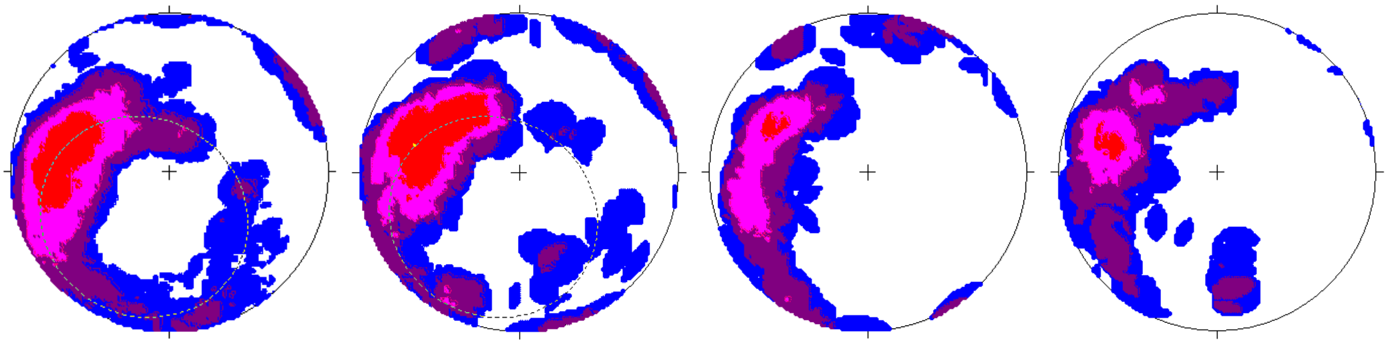


The only solution to controlling measurement errors is to institute a regime of care and ensure that the people doing the measurement are aware of the importance of accuracy and have pride in their work.

Orientation Confidence Scores for core runs

An element of quality control can be introduced by assigning a confidence level to the precision of the orientation mark within each run of core. One relatively objective system that I have seen used is to assign a confidence number representing the number of successive core runs across which the orientation mark can be matched. The plot at right shows a set of 750 real data with a pronounced small circle distribution (indicating a severe orientation problem). The plots below show the same data plotted according to the confidence level as defined above , but split into data sets that (from left to right) successively have confidence levels of 1, 2, 3, & 4 or higher (where the higher number denotes greater confidence). Note that it is only when three successive runs or more occur that the data is relatively stable and a confident pattern emerges. In other words, in this drill program, 76% of the data are unreliable, and unless some confidence assignation is applied, none of the data at all are reliable!





1 (55% of the data)	2 (21% of the data)	3 (12% of the data)	4 (12% of the data)

A systematic ORI confidence scoring procedure for each run of core

[*Note that the procedure outlined here supercedes a similar procedure described in earlier versions of this manual*].

The following outlines a semi-automatic systematic procedure for both minimising and quantifying the precision of the core mark-up. It is based on combining a number of the best practices I have seen and, because elements of it involve statistical decisions, it should be at least partly overseen by a geologist.

- Align the first run of core with the drillers BOH mark at the top. Using the procedure described above, dock as many contiguous runs of core as possible up to some arbitrary limit (say 8).
- Stop when a natural non-dockable break occurs or you exceed the run limit you have set)
- Starting with the driller's bottom-of-core mark in the first run, draw a preliminary BOH 'zero' line in pencil along the rest of the docked core
- At each subsequent driller's bottom-of-hole mark record the mismatch, in mm, between this initial pencil line and the bottom-of-core mark. (I'll call this the 'spin'). Record the spin (mismatch) as mm left or right of the initial BOH line (looking down-core).
    - The amount of angular ‘spin’ that this mismatch represents depends on the core diameter. For HQ core, 5.5mm represents 10° of rotation (spin) from the previous mark.

- The amount of spin that can be tolerated depends on company protocols for the type and complexity of the deposit.
- In complex terranes it should be no more than ~10-15°.

- Assign -ve values to those left of the initial line; +ve to those right of the line (looking down-core). Record any other BOH marks lying on the zero line as 0 in the zero column (e.g. example 2).
- When the spin of all of the dockable runs are recorded calculate the raw mean of all of the spins. This mean will be a number of mm left (-ve) or right (+ve) of the initial BOH line.
- Examine the array of recorded 'spins' looking for a single natural cluster (the mode) and identify outliers. Exclude outliers by recording a Y in the Excluded column. Use the raw mean as a rough guide only to identifying the mode.
  - Outliers are those with a spin >10° (say) from the mode. In example 2 the mode is near zero, so exclude both the values -11 and -12 even though the raw mean (-3.1) is less than 10mm from both of these excluded values. In some circumstances, the zero value of the initial BOH mark may be an outlier (example 3).
- If the spins are random and there is no clear mode, then exclude any values that are more than 10mm (say) from the raw mean (example 4). If there are two distinct clusters (modes) at least 10mm apart then exclude all of the smallest set. Exclude all of either set if both modes contain the same number of marks - this will automatically assign a low score (example 5).
- Calculate an Adjusted Mean value of the spins for all the runs that are not excluded.

Starting back at the first run of core, mark the location of the Adjusted Mean, which is in mm left (-ve) or right of the original zero mark (looking down-hole). *Draw a new permanent BOH line along the entire length of docked core, marking down-hole barbs on each core segment.*

MARK ID	mm Right	zero	mm Left	Excluded		
1		0				
2			-2			
3	3				No of runs:	5
4	5		-6		Range:	11
5					Raw Mean:	0.0
6					No.excluded:	0
7					Adjust.Mean:	0.0
8					ORI score:	**5**

MARK ID	mm Right	zero	mm Left	Excluded		
1		0				
2			-12	Y		
3	3				No of runs:	7
4			-4		Range:	15
5	2				Raw Mean:	-3.1
6			-11	Y	No.excluded:	2
7		0			Adjust.Mean:	0.2
8					ORI score:	**3**

MARK ID	mm Right	zero	mm Left	Excluded		
1		0		Y		
2	8					
3	15				No of runs:	6
4	12				Range:	21
5	13				Raw Mean:	7.0
6			-6	Y	No.excluded:	2
7					Adjust.Mean:	12.0
8					ORI score:	**3**

MARK ID	mm Right	zero	mm Left	Excluded		
1		0				
2	4					
3	12				No of runs:	6
4			-10	Y	Range:	23
5			-6		Raw Mean:	2.2
6	13			Y	No.excluded:	2
7					Adjust.Mean:	2.5
8					ORI score:	**3**

MARK ID	mm Right	zero	mm Left	Excluded		
1		0				
2			-12	Y		
3	15			Y	No of runs:	6
4	3				Range:	27
5			-4		Raw Mean:	-1.5
6			-11	Y	No.excluded:	3
7					Adjust.Mean:	-0.3
8					ORI score:	**1**

- Assign a BOH Confidence Score between 1-5. This process can be automated in a spreadsheet as shown. The algorithm used here for calculating the score is: Assign a value of 1 if the number of excluded runs is more than 40% of the total number of runs.
- Otherwise, if the number of non-excluded runs is more than 5, assign a score of 5, else subtract the number of excluded runs from the total number of docked runs in the set.

- Single runs of core that can't be docked to adjacent runs will automatically have a score of 1.
- This confidence score is assigned to all structural data within the scored interval

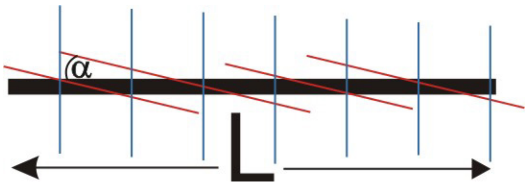
  (The range of core spin should be transmitted back to the driller as part of the QA/QC process)

	A	B	C	D	E	F	G
1	MARK ID	mm Right	zero	mm Left	Excluded		
2	1		0				
3	2			-2			
4	3	3				No of runs:	3
5	4					Range:	5
6	5					Raw Mean:	0.3
7	6					No.excluded:	0
8	7					Adjust.Mean:	0.3
9	8					ORI score:	**3**

```
=COUNT($B2:$D9)
=MAX($B2:$B9)-MIN($D2:$D9)
=AVERAGE($B2:$D9)
=COUNTA($E2:$E9)
=(SUMIFS($B2:$B9,$E2:$E9,"")+SUMIFS($D2:$D9,$E2:$E9,""))/($G4-$G7)
=IF((G4-G7)/G4<0.6,1,IF(G4-G7>5,5,IF(G4>5,5-G7,G4-G7)))
```

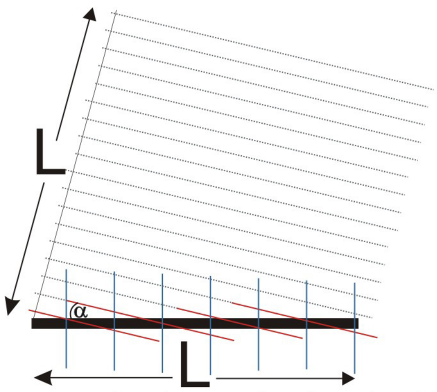
The procedure outlined can be streamlined so that it can be done efficiently by technical staff, particularly if the entries and calculations are done digitally. However, the process of estimating a mode and eliminating outliers should at the very least be checked by a geologist.

Data bias



For distinctly spaced planar structures, such as faults, joint sets, and veins, there is a potential statistical frequency bias caused by the linear nature of drill core. The closer such features are oriented to the core axis the less likely it is that they will be intersected. In the diagram at right, the red set of planes is intersected four times in a given length (L) of core; the blue set seven times. However it is clear that the red surfaces are closer spaced, and thus have a greater true frequency, than the blue set.

This bias can be partly overcome statistically by applying a correction factor (known as the Terzagghi bias correction) to the apparent frequency. The correction factor, 1/sin α, recalculates what the frequency would be if the measurement line was perpendicular to the plane. Alpha is the angle between the planar feature and the core axis and is the same as the alpha angle measured in oriented core procedures.

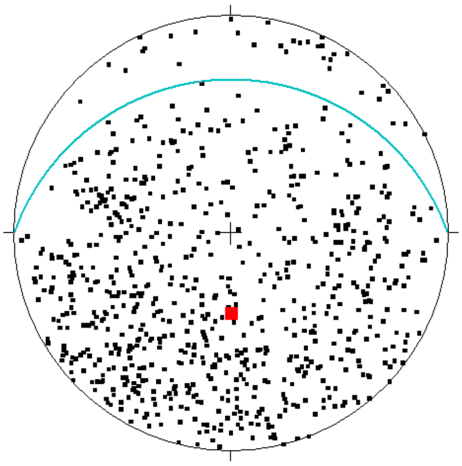


n (app) = 4; n (true) = n(app)/sin α = 18

n (app) = 7; n (true) = n(app)/sin 90 = 7

This correction procedure should not be applied to planes where the alpha angle is less than about 10°, as the sin α value increases rapidly, and the correction factor becomes infinitely large. Thus, there may remain an orientation zone within 10-15° of the core axis, which substantially underestimates the true frequency of **spaced** data.

This underestimation for low alpha angles can produce a great circle void normal to the core axis in stereographic plots of poles to the measured planes and lead to a misinterpretation of the orientation patterns. This void is not to be confused with the small circle patterns produced by orientation errors discussed in the next section.



Stereographic plot of 762 randomly oriented microfaults measured in drillcore from holes plunging 60°S (red square).
Note the great circle void representing planes lying within about 15° of the core axis.

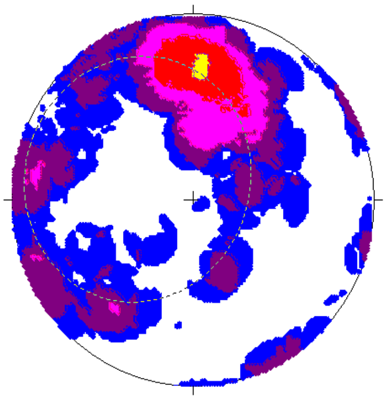
The bias procedure described above is only valid for spaced data, where the spacing is greater than the width of the core. Structural fabrics such as bedding lamination or foliation, which are penetrative (i.e. pervasive) at the core width scale, should **not** be corrected in this way, provided that steps are taken to ensure that the low angle surfaces are measured at the same interval as the higher angle surfaces. However I commonly see a bias introduced by avoiding measuring such fabrics when the alpha angle is close to zero (i.e. the fabric is close to parallel with the core axis). Presumably the lack of a well defined elliptical intersection with the core is the perceived problem. This measurement bias can be avoided by simply being aware of the problem and taking positive steps not to miss such data. It might require having to estimate the location of the apical trace of the ellipse in order to determine the beta angle (as described in an earlier section), but the estimation error should be moderately low.

CORE SHED LAYOUTS

A well laid out core layout space is crucial to producing reliable results from core (and making the life of core shed personnel more pleasant). The images below are from one of the best of these that I have seen (it is in SE Asia). The core tray inspection/layout tables were sets of rollers, and movable rollers were used to transport core boxes from holding racks to the inspection tables; between the tables, and into the weighing and cutting rooms. Hose lines were strung overhead. Angle iron racks for laying out the core for orientation mark-up ran the whole length of the inspection tables allowing 5-10 runs of core to be docked simultaneously.

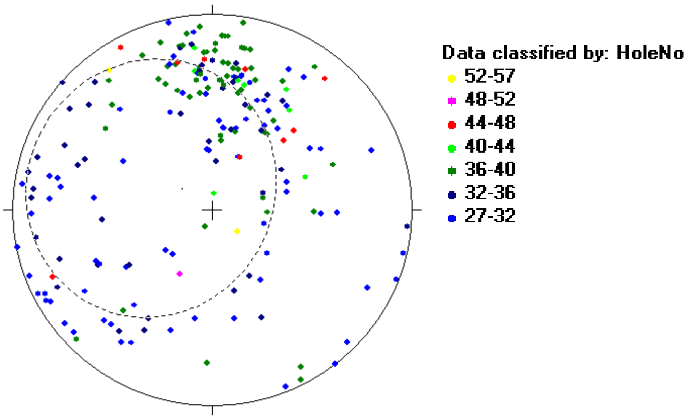
ORIENTATION DATA ANALYSIS USING CLASSIFIED STEREOGRAPHIC PLOTS

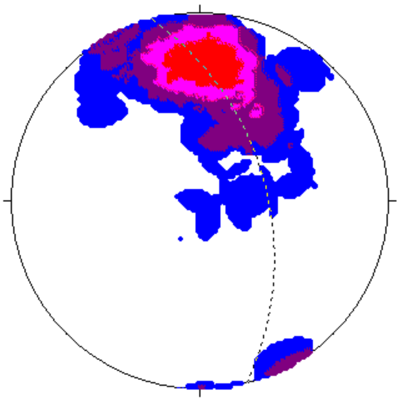
Oriented core is required in a variety of terrane and prospect types. It is critical to assessing 3D geometry in prospects containing moderate to strong folding, or arrays of variably oriented faults or shear zones, or of variably oriented mineralised vein systems. It is very important in the analysis of fracture patterns for geotechnical assessment and it is very useful in the statistical analysis of vein patterns.



To be useful, measured orientation data should be abundant enough to allow statistical analysis of the data as well as supplying orientation controls on sections. Examples of frequency analysis are shown above by the stereographic plots produced by GEOrient©* software. These plots have been produced by copying processed oriented data dip and dip direction columns directly from drill spreadsheets and database tables and then pasting them into GEOrient.

In addition to the usual stereographic plots of data frequency, GEOrient also contains a class of **classified stereo** plot in which the plotted poles can be colour coded according to other attached values or information. One way I have used these plots is to determine whether specific drillholes have contributed to suspect orientation data or whether the misorientation is random. For example in the plot at right, the same 213 foliation data that are shown in the contoured plot above have been replotted, but now colour-coded (that is, classified) according to which set of drillholes each item of structural data has come from. Note that it is clear that the blue-coloured poles (DDH27-36) contribute unduly to the small circle distribution indicating suspect data, whereas the light and dark green poles (DDH37-44) appear to be in the unimodal cluster expected of good data. There are few foliation data from the other drillholes (DDH45-57) but the orientation of these holes also appears to be suspect. Thus in this instance it is clear that there is a very specific sequence of drillholes (27-36) in which the orientations are all suspect – and only **26%** of the holes contain verifiably reliable data. When the foliation data are plotted using only the 'good' drillholes (figure, right) the small circle distribution has disappeared and the data are quite interpretable.

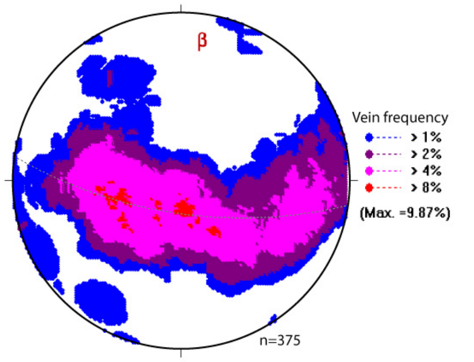




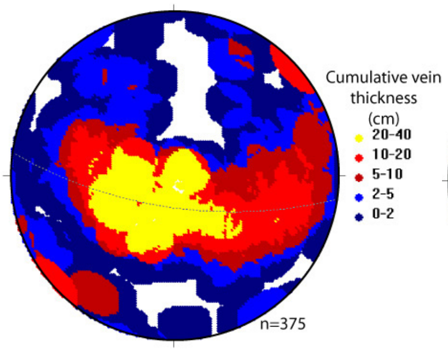
A powerful extension of Classified stereographic projections that I have developed in GEOrient* are **Numeric stereographic projections**. In these plots, instead of the orientation density being gridded and contoured, the values associated with the orientation data are gridded and contoured. Such plots can show contours of either the orientation distribution of the mean value or of the cumulative sum of the numeric data. For example, I have found these types of plots particularly useful in the analysis of the mineralisation potential of vein arrays, where the values plotted are vein thickness and assay values.

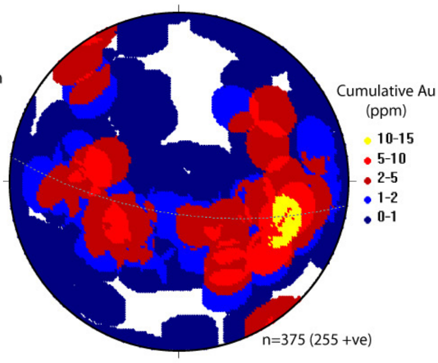
*available from: https://www.holcombe.net.au/software/

For example, the typical frequency plot shown on the right shows the orientation distribution of normals (poles) to sheeted veins derived from oriented drillhole data. The great circle girdle reflects the uniformly fanned nature of the veins (with the beta symbol parallel to the axis of fanning).

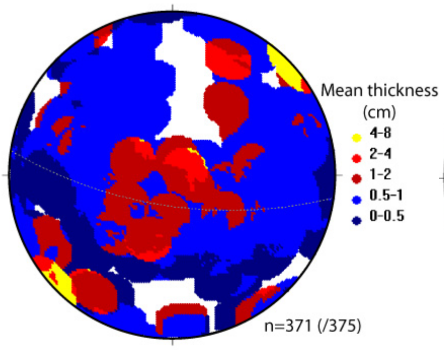


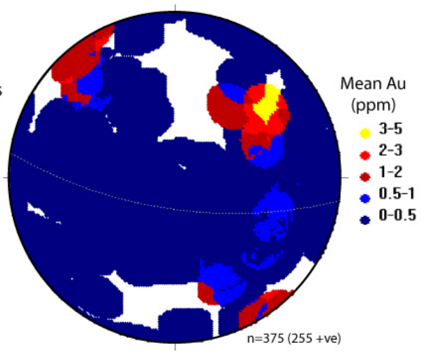
The plots shown below are numeric stereographic projections that show the cumulative vein thickness (top left) and cumulative gold values (top right) in the same data. Note that the greatest accumulation of vein widths does not correspond to the maximum accumulation of gold. Clearly these are not simply fanned coeval veins but two different vein systems that overlap in orientation. So for example, drilling should be conducted so as to optimise intersection with the gold-bearing veins.

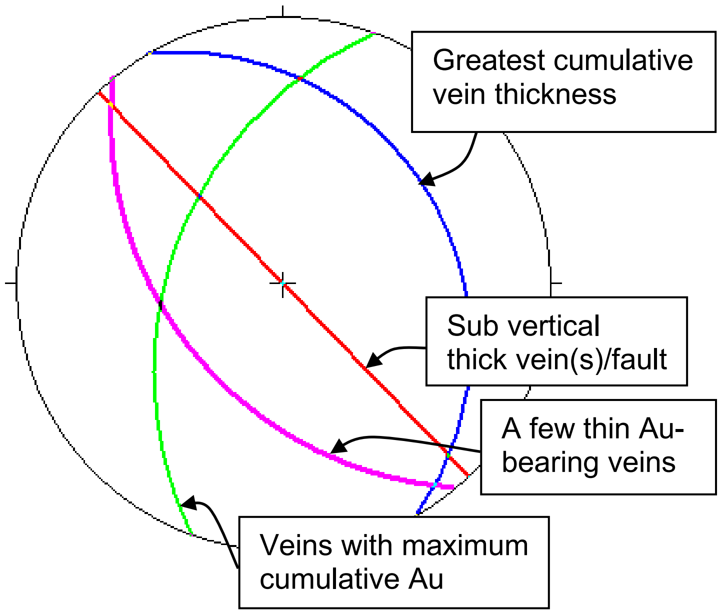




More information pertinent to the vein system can be derived when the plots that show the mean values are also considered (right). For example, the mean thickness of veins is moderately uniform except for those with normals that are subhorizontal and trending northeast. This orientation corresponds to a very low frequency of data (from the frequency plot at top), so this abnormally high thickness value must correspond to only one or two veins at most. The mean gold values are uniformly low, again except for a maximum in the northeast quadrant. Notably, the mean gold maximum is about 35° to the mean thickness maximum, suggesting that the gold is most likely associated with thin extensional veins related to a fault that is now occupied by a thick vein (or veins).







WRAP-AROUND PROTRACTORS FOR ORIENTED DRILLCORE MEASUREMENTS

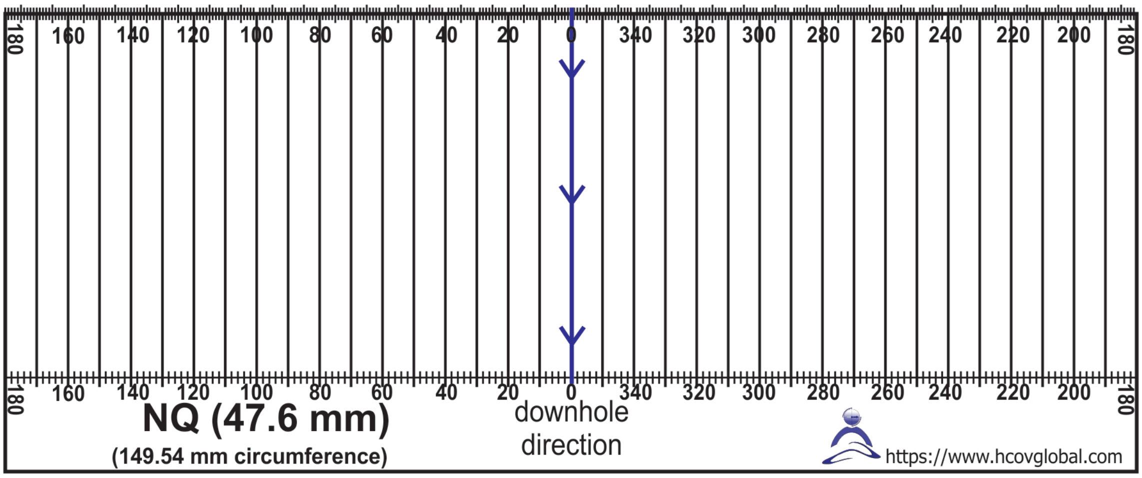
It is a relatively simple matter to construct a wrap-around protractor to measure beta angles in oriented core using a software drawing package. The procedure is to measure the circumference of the core and divide it by 360 to calculate the spacing of a 1-degree beta angle. A set of parallel lines is then drawn, using a convenient spacing (eg. 10 degrees).

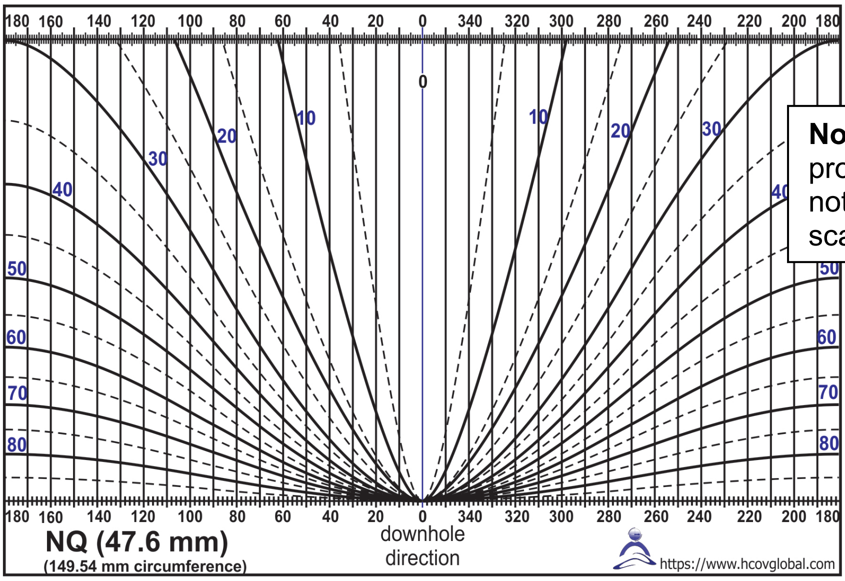
Shown below is one such protractor constructed for 47.6mm NQ core. (Note that with multiple core barrels, core such as NQ-3 can have different diameters). Once constructed the protractor is printed onto stiff plastic film using a laser printer. (Laser printers give a finer, more durable line than most ink-jet printers). I use HiClear™ Crystal Clear 200 micron PVC Report Cover for the film.

An accompanying downloadable brochure: 'Oriented drill core Protractor Templates' can be downloaded from our website at:
https://www.hcovglobal.com/downloads and contains printable protractors for common core sizes. Ensure that the printer does not rescale the pages (set the page scaling to NONE in Print manager).

Two types of protractor are available:

- a simple wrap around beta angle protractor (shown at full-scale below). Use an ordinary protractor as shown in this manual to measure the alpha angle;
- Combined alpha-beta wrap around protractor. Although this template can be useful for larger core, the lines tend to be a little too busy for easy visibility, and the larger width of the protractor, necessary to show the alpha angle curves, makes it a little awkward to use.





Note: This protractor image is not to a standard scale

ABOUT THE AUTHOR

Rod Holcombe (PhD, FGSA) is an Adjunct Professor of Structural Geology at the University of Queensland and a founding member of HCOV Global, a consortium of consultants to the minerals exploration industry.

Rod is a specialist in the structural analysis and 3D modelling of complex metamorphic terranes and shear zones with over 45 years' experience in Precambrian and Phanerozoic terranes in Australasia, south-east Asia, North and South America, East and West Africa, northern Europe, Siberia and the Russian Far East, and Tethyan systems of the Balkans and sub-Caucasus.

Rod is the author of a textbook *Mapping and structural geology in mineral exploration: where theory hits the fan* (distributed from: https://www.holcombe.net.au/book/rodh-book.html);,
a number of software packages, both free and commercial, (distributed from: https://www.holcombe.net.au/software/), as well as other professional products distributed from: https://www.hcovglobal.com/downloads

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Nick Oliver (PhD; FSEG; M AusIMM; M GeolSocAm; M GeolSocAus; MSGA), a structural and hydrothermal systems geologist, particularly in complex environments.

Tim Coughlin (MSc, PhD, FAusIMM), a structural geologist with particular experience in frontier target generation and risk analysis in emerging and developing countries.

Rick Valenta (PhD, FAusimm, P. Geo, MAICD), a structural geologist and specialist in the structural interpretation of geophysical datasets, 3D modelling of mineralised systems, regional project generation, and advanced exploration of known prospects.

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