ORIENTED DRILLCORE: MEASUREMENT AND CALCULATION PROCEDURES FOR STRUCTURAL AND EXPLORATION GEOLOGISTS

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DRILLCORE ORIENTATION TYPES

Unoriented drillcore
During core drilling, runs of core (commonly ~ 3 metres long) are extracted from a core barrel at a time. 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.

Oriented drillcore
Various mechanical methods are available during drilling to mark the lowermost point on the top face of a run of core. As the process generally uses gravity to find the lowermost point, the process is generally only feasible in holes with an appreciable plunge. The orientation mark, along with knowledge allows the core to be uniquely oriented in space.

'Oriented' core has an 'orientation mark' (‘OM’) along the core marking either the lowermost or topmost line along an inclined drillhole (called the ‘bottom mark’ (‘BM’) or ‘top mark’, respectively). 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 measurement and plotting procedures.

Partially oriented drillcore
In nothing else was 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 the 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.

'Partially oriented' core is core in which a local reference plane whose orientation is well known (such as bedding, cleavage, etc) can be recognised. 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 solve the orientation of the unknown plane.
Drillcore angle conventions

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

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

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 angle can also refer to the angle between the core axis and a line that passes through the centre of the core).

- **beta angle**: the angle between a reference line along the core and the ellipse apical trace measured in a clockwise sense (0-360°). 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°).
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) $\alpha$ – angle between plane and core axis; (ii) $\beta$ - angle from orientation line measured in a clockwise sense around the core; and (iii) $\gamma$ - angle from ellipse long axis to a line lying in the ellipse plane.

Measurement of alpha angle

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

2. Using 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 65° read from trace of bedding parallel to alpha curve.*
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 in order 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. 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 295°.

*‘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.
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 (http://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.
1. Set the measurement conventions:

- Whether drill-hole orientation is in terms of plunge or zenith
- Whether drill-hole orientation uses a –ve angle for upward holes or downward holes
- Whether the orientation mark is a top mark or bottom mark
- Whether the alpha angle used is between the core axis and the ellipse long axis or the ellipse normal (the delta angle)
- Whether beta and gamma angles are measured relative to the up-hole or down-hole end of the ellipse long axis
- Whether gamma angles are measured as a 360º clockwise angle or as a ±180º angle

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.
**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 reference line for measuring the beta angle.

**Step 2:** Count the beta angle along the measurement plane great circle, clockwise from the ‘bottom mark’ reference line. Draw the great circle through this point and the core axis. This is the plane that contains the normal to the ellipse (the unknown plane).

(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 calculated 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.

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**The conventions assumed for the following description are:**

- **Alpha** – acute angle between core axis and ellipse long axis
- **Beta** – angle clockwise from ‘bottom mark’ of bottom of ellipse of unknown plane (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.
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 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 ~240):
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.

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.

Put simply the ‘rule’ is:
for beta angles from >90 and <270 measure the delta angle from the core axis away from the calculated beta intersection line in the measurement plane;
for all other beta angles measure the delta angle from the core axis toward the calculated beta intersection line in the measurement plane.
WRAP-AROUND PROTRACTORS FOR ORIENTED DRILL CORE 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 (e.g., 10 degrees). Shown below is one such protractor constructed for 63.5mm HQ core. (Note that with multiple core barrels core such as HQ can have slightly different diameters). Once constructed the protractor is printed onto stiff plastic film using a laser projector. (Laser printers give a finer, more durable line than most ink-jet printers).

An accompanying downloadable brochure: ‘HCA Oriented Core Templates’ can be downloaded from our website at: http://www.holcombecoughlin.com/HCA_downloads.htm 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 as 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.

![Protractor Diagram](image-url)
ABOUT US:

Holcombe Coughlin and Associates is a consortium of two independent European and Australian-based consultancies specialising in the application of modern structural techniques to the global resource industry. We operate globally from both Australian and European bases.

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Computer applications and other products developed by Rod for use by structural and exploration geologists can be found at:
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