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A method for measuring the orientations of planar structures in cut core

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ABSTRACT

Exploration drill core is commonly cut in half for assay purposes soon after acquisition. Structural measurements from half core are generally less accurate or more difficult to make using existing techniques than on whole core. This paper proposes a method to determine the orientations of planar features from half core, by measuring two lengths and one angle. The method is rapid, simple and has errors of less than 2° in suitable core. It is also robust for core that is not cut exactly in half. Detailed structural studies can now be made at later stages in exploration after core has been cut, as illustrated here by kinematic analysis of SC and SC' fabrics.

1. Introduction

Measuring orientations of structures in orientated drill core is an essential part of most exploration programs for mineral deposits. Tens to hundreds of kilometres of drill core might be obtained in order to prove a resource. Drill core may contain the only direct information about the structures that control the orientation and location of the deposit, especially in areas of poor exposure, or where the deposit is under cover. Measurements from drill core are also vital in engineering and geotechnical applications, and in scientific drilling (e.g. Tembe et al., 2006; Louis et al., 2008).

Several methods exist for determining the orientation of planar structures from drill core. The most widely used method is probably the measurement of two angles (usually denoted α and β) to specify the orientation of planes relative to the drill core axis and an orientation line on the core, generally marked at the lowest point around the circumference of the core (e.g. Zimmer, 1963; Laing, 1977; Stanley and Hooper, 2003; Holcombe, 2008). Measurements can also be made relative to fabrics of known orientation (e.g. Hinman, 1993; Scott and Berry, 2004), or from cores that intersect the same structure from different orientations (e.g. Versteeg and Morris, 1994). Methods using unorientated slabbed core to constrain the orientation of planar structures have been described by Hesthammer (1998) and Hesthammer & Hendon (2000). A popular alternative is to re-orientate the core in the position from which it was drilled, and to take structural measurements from the core with a compass, as though the core was an outcrop (e.g. Marjoribanks, 1997). Core can be re-positioned using a simple frame (a "rocket launcher"), or a sand box. A new photographic method has been developed recently (https://www.groundmodellingtechnologies.com/).

These methods are designed to work with full core as retrieved directly from a drill hole. However, in most mining and exploration circumstances, critical intervals of the core are cut in half as soon as possible after drilling for assay purposes. Structural measurements are taken in the brief interval between drilling and sampling, and are rarely as comprehensive as needed. The remaining half core is stored. It is often necessary to revisit this core to collect more detailed measurements, particularly as hypotheses advance about important structures that may control mineralization as the ore body is delineated and mined. However, cut core poses problems for traditional techniques of core structural analysis. Where the half core does not include the lowest point of a plane, β can not be measured directly. Subject to this limitation, the α–β method can be used on half core if a special transparent template is constructed (Rob Scott, pers. comm.), which needs to be customised to the particular core size. Estimation of planar orientations in the rocket launcher or sand box from cut core are generally more difficult and less accurate than for whole core.

This study proposes and tests a new method to acquire accurate orientations of planar features from core that has been cut, which

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requires only three simple measurements: two lengths and an angle. It is comparable in simplicity to the $\alpha - \beta$ method used on full core, and does not require a template.

2. Principle

The orientation of planes is first measured relative to the core, then converted to real orientations using the direction and inclination of the drill hole. An interim frame of reference is used for the initial measurements, in which the bottom-of-core line is vertical and assumed to be at the North end of the core. Fig. 1 shows the essential geometrical elements, and definitions of terms and quantities are given in Table 1. The objective is to calculate the dip and dip bearing of a plane P (Fig. 1). Lines ***M'N*** and ***O'N*** are two vectors that lie within P. The normal to P, ***n***, is given simply by their cross-product:

$$\boldsymbol{n} = \boldsymbol{M'N} \, x \, \boldsymbol{O'N} \tag{1}$$

The positions of ***M*** and ***O*** can be measured simply and quickly with a set square or ruler relative to the point ***N***, taking down-hole distances from ***N*** as positive. Fig. 2 is a photograph of half core with ***N***, ***M*** and ***O*** marked up for a plane, as shown in Fig. 1a. These values can be converted to plunges (*P*) and trends (*T*) of vectors ***M'N*** and ***O'N*** by simple trigonometry, assuming that the core is vertical with the bottom-of-core mark in the North position (i.e. the interim frame of reference):

$$T_{O'N} = 90 + \beta/2 \ \text{ If } \ \text{NO} < 0(\text{Fig. 1b}) \tag{2}$$

$$P_{O'N} = \text{Tan}^{-1}(\text{NO}/2r \ \text{Sin}(\beta/2))(\text{Fig. 1c}) \tag{3}$$

$$T_{M'N} = \beta \ \text{ if } \ \text{NM} < 0(\text{Fig. 1a}) \tag{4}$$

$$P_{M'N} = \text{Tan}^{-1}(\text{NM}/2r)(\text{Fig. 1d}) \tag{5}$$

Appropriate adjustments are made to the formula to deal with positive values of NO, NM. The formulae also require measurement of β, the angle measured clockwise when viewed down-hole from the bottom-of-core line to near edge of core (Fig. 1), and the radius of the core, r.

The normal to P in the interim frame of reference is given by Eq. (1). The final, real orientation of P is given by rotating ***n*** back into a geographic frame of reference using a rotation matrix derived from the orientation of the drill hole, which is acquired using standard gyroscopic, electronic or camera tools (e.g. Paulsen et al., 2002). Note that ***NO'*** is undefined for $\beta = 0$ or 180°: the method as described only works when the core is not cut along the bottom-of-core mark. The latter is standard industry practice, so as to preserve the orientation mark.

An additional measurement is necessary for core that is not cut exactly in half. The top of such an oversize half core is shown in Fig. 3a. The vector ***O'N*** will be given correctly by measurements of NO and β substituted in Eqs. (2) and (3), but the flat face is no longer parallel to β, and distance M′M is no longer equal to the diameter of the core. Equations (4) and (5) must be rewritten:

$$T_{M'N} = \beta - \text{Cos}^{-1}(M'M/2r) \ \text{ if } \ \text{NM} < 0 \tag{6}$$

$$P_{M'N} = \text{Tan}^{-1}(\text{NM}/M'M) \tag{7}$$

For undersize half core (Fig. 3b), Eq. (6) becomes:

$$T_{M'N} = \beta + \text{Cos}^{-1}(M'M/2r) \ \text{ if } \ \text{NM} < 0 \tag{8}$$

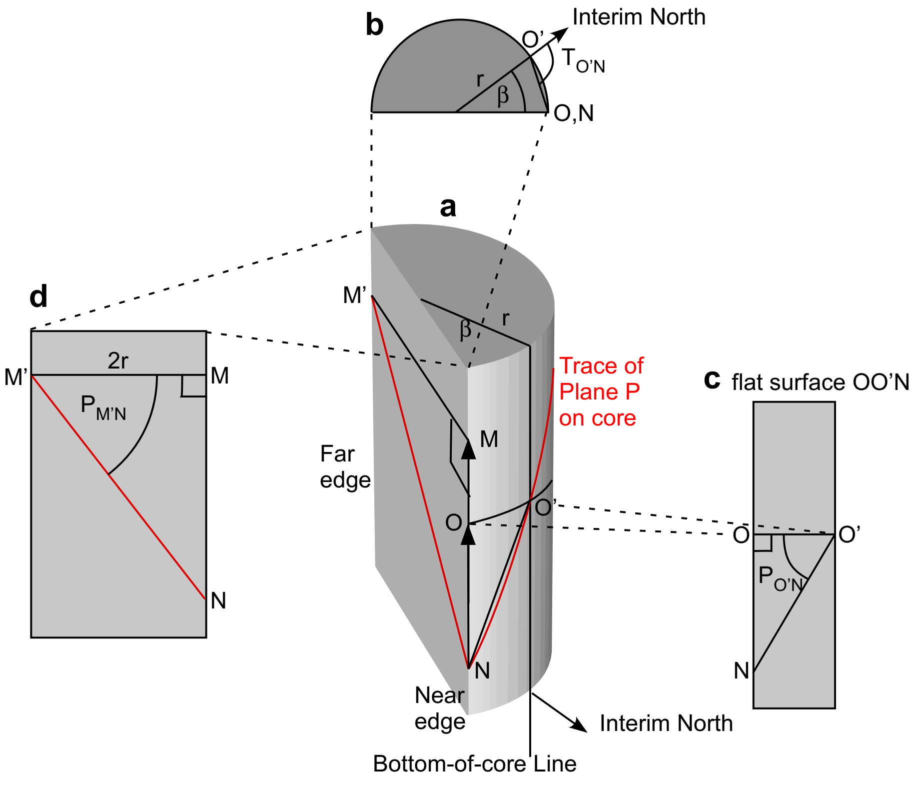

Fig. 1. Appearance of half core and points used for calculations. a) View of half core with trace of plane P. b) View of top of half core. c) View of surface OO'N. d) View of flat face of half core.

Table 1
Definitions of terms and quantities. Refer to Fig. 1 for further explanation. Lengths are measured positive down-hole.

Term/ Quantity	Definition
Near edge	Edge of half core nearest bottom-of-core line
Far Edge	Edge of half core furthest from bottom-of-core line
β	Beta, smallest angle measured clockwise when viewed down-hole from bottom-of-core line to near edge of core.
$M'N$	Trace of plane P on flat face of half core
M'	Uphole end of line $M'N$
M	Projection of M' across flat face of core perpendicular to core axis
N	down-hole end of line MN
O'	Point at intersection of plane with bottom-of-core line
O	Intersection of the plane P perpendicular to core axis that passes through O′ with the edge of the core nearest the bottom-of-core mark
r	Radius of whole core
$\boldsymbol{n}$	Normal to plane P

3. Results

The orientations of planes derived from the above method were compared with measurements of the same planes using a rocket launcher. The latter measurements could only be obtained for a limited number of planes, because most planes can not be measured at all accurately in the rocket launcher on half core. Fig. 4 is a lower hemisphere, equal area stereoplot of the poles to planes given by this method (black dots) compared to rocket launcher orientations (red triangles). The accuracy of the rocket launcher measurements is unknown, but there is a good match. This correspondence probably indicates that both methods are reasonably accurate.

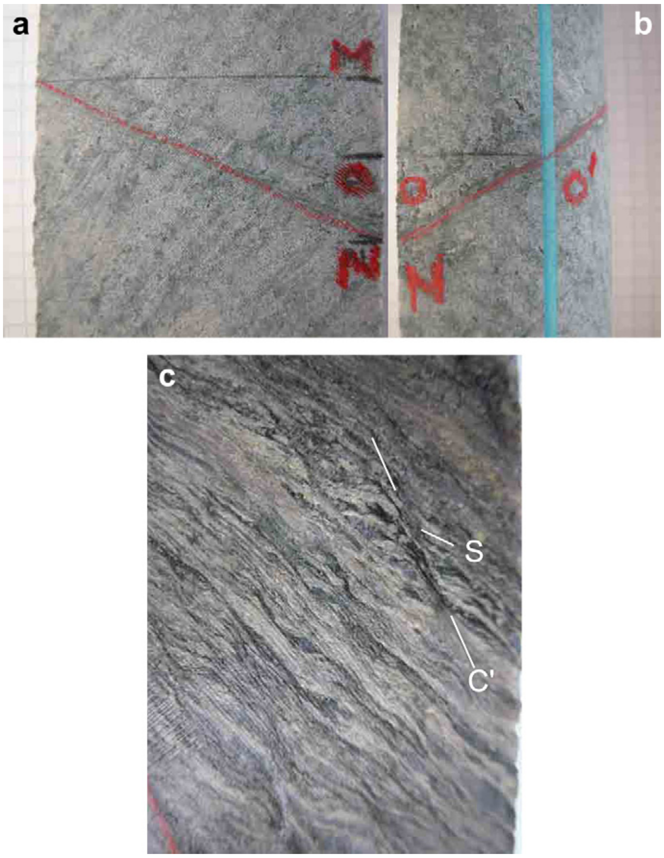

Fig. 2. Half core from Tropicana Gold Deposit. a) View of flat surface of core with plane marked in red and points M, O and N as shown in Fig. 1. b) View of curved surface of core. The blue bottom-of-core line is the interim North direction. c) SC' fabrics showing a down to the right sense of shear.

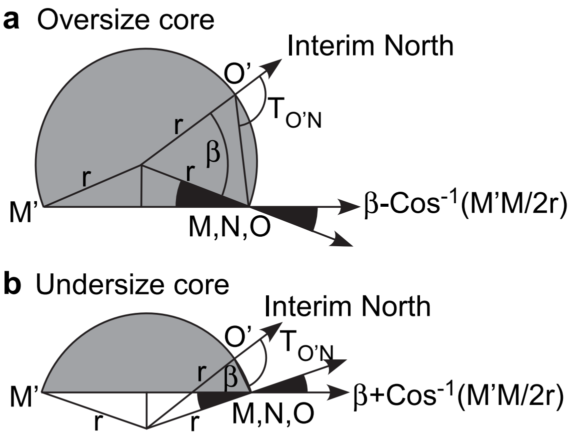

Fig. 3. Geometries of a) Oversize and b) Undersize core. The solid black angle in both cases is Cos^{-1} (M′M/2r).

4. Error analysis

Errors related specifically to the application of this method can be assessed by the angular difference between poles to planes calculated with and without errors. The two types of possible error are:

1. *Measurement of NM, NO* – These distances should be measurable to within 1 mm, but there are sometimes problems in accurately defining the planes to be measured, especially if they are not perfectly flat. These can inaccuracies can generate measurement errors for NM and NO.
2. *Measurement of β* – β is measured from the bottom-of-core line, which may be rather thick, and many core protractors are only graduated in 5° increments. In favourable circumstances, combinations of these factors may lead to errors of 2°. Smaller core diameters and thicker marks will incur larger errors.

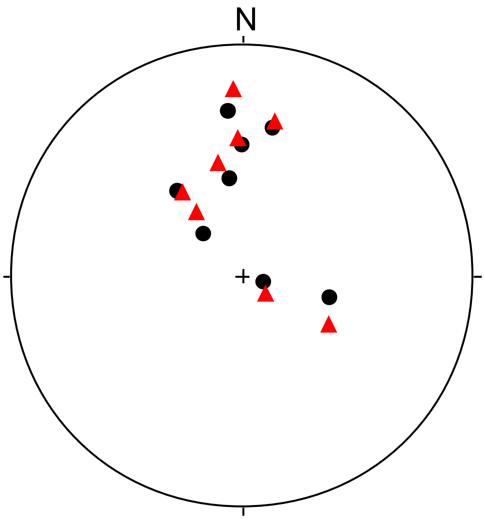

Fig. 4. Stereoplot of measurements made by the method described here (black dots) compared to measurements of the same surfaces by the rocket launcher (red triangles). Equal area, lower hemisphere stereoplot.

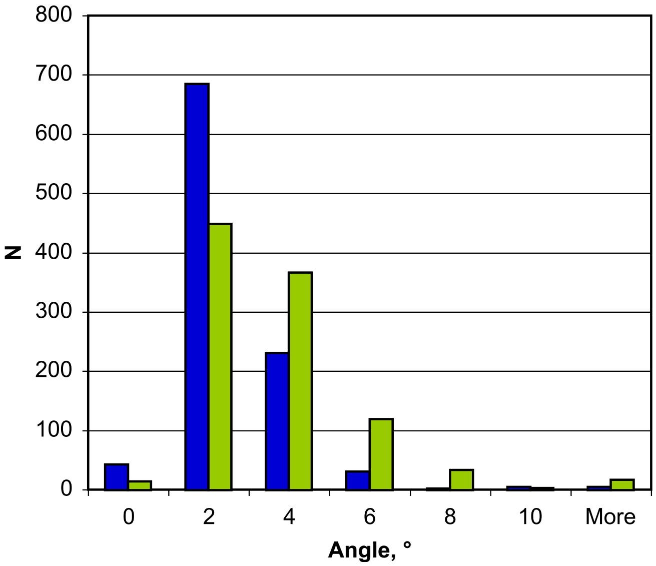

Fig. 5. Histogram of errors from a set of 1000 randomly generated β, NM and NO measurements, with the following ranges: $0 \leq \beta < 90$, $-50 \leq$ NM, NO $\leq +50$. Errors were generated by randomly perturbing NM and NO by 1 mm, and β in the range 0–2° (blue bars) and 0–4° (green bars).

The effect of these errors was investigated on a set of 1000 randomly generated β, NM and NO measurements, with the following ranges: $0 \leq \beta < 90$, $-50 \leq$ NM, NO $\leq +50$. The orientation of poles to this original data set were calculated by the method described above, and then errors were simulated by randomly adding or subtracting 1 mm from the NM and NO measurements, and 0–2° (favourable circumstances) or 0–4° (less favourable) from the β measurements. The poles to the measurements with errors were calculated, as well as the angular difference between these poles and the original data set (Fig. 5). The mean value of the errors with 2° variation in β measurements is 2°, increasing only to 3° with 4° variation in β measurements. Both "error" populations are strongly positively skewed.

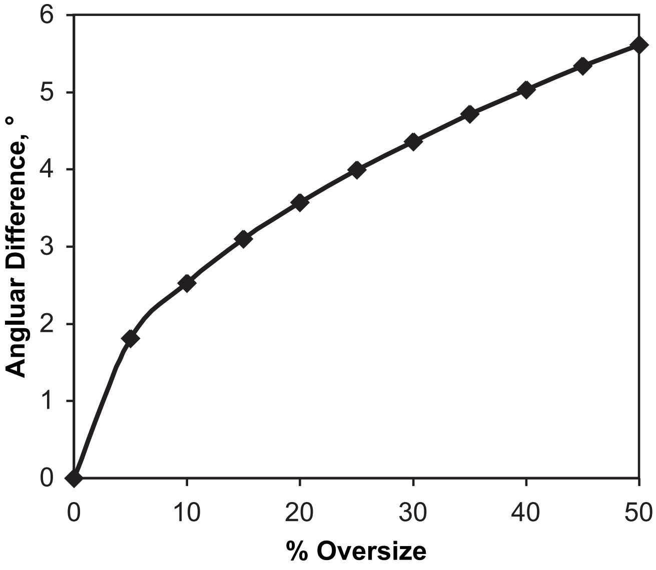

Fig. 6. Average error from the same data set as Fig. 5 as a function of percentage oversize core (abscissa). Even for core that is 50% oversize, the errors are only 6°.

The errors for specific geometries vary considerably. Experiments conducted by varying NM and NO by the previous values suggest the following generalizations: Errors in NO have larger effects than errors in NM. Errors in one of the lengths have little effect at large values of the other length; and errors in NO have more effect at small values of β than at large ones. Errors in β have little effect at small values of NO.

Although the effect of over- or undersize core cutting are accounted for by Eqs. (6)–(8), these equations can also be used to calculate the error introduced by using the simpler measurements for exact half core and Eqs. (2)–(5). Using the same set of 1000 random measurements of β, NM and NO above, the effects of up to 50% oversize core were investigated in 5% steps. The results shown in Fig. 6 illustrate the angular difference between orientations of planes calculated with and without considering the oversize core effect. Even where cut core is more than 50% larger than half core, the average difference is only 5–6°. The reason for this low value is that the method inherently corrects oversize core for one of the vectors (***O'N***) used to calculate the orientation of the plane. Measurements made using the simple method described above will scarcely be affected by cuts that are not through the centre of the core.

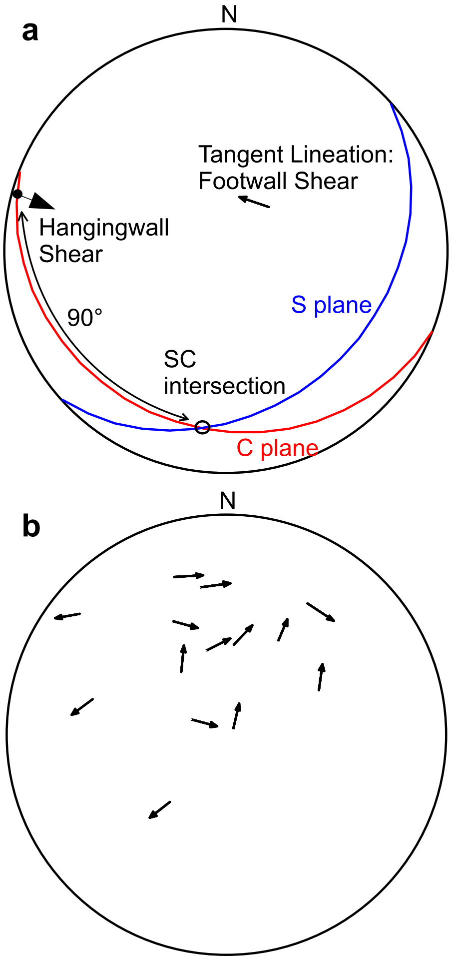

Fig. 7. a) An example of S and C plane measurements made on core using the method described here. The shear direction is taken as 90° from the SC intersection within the C plane. b) A tangent lineation plot of 14 measurements made by this method.

5. Application

Application of the half-core method is well illustrated by analysis of SC and SC' fabrics (Fig. 2c). The fabrics are developed in a biotite–sericite ± chlorite alteration assemblage from a quartzofeldspathic gneiss hosting the 5 Moz Tropicana gold deposit in Western Australia (Doyle et al., 2009). The scale of the fabrics is sufficiently coarse that S, C and C′ planes can be separately identified and marked up on the core, and measured as distinct planes by the half-core method. Each pair of measurements can then be used to make a kinematic analysis as shown in Fig. 7a. The intersection between the S and C or C′ planes is calculated and the point within the C or C′ plane at a pitch of 90° from the SC or SC' intersection is taken as the shear direction (e.g. Blenkinsop and Treloar, 1995). The angular relations between the S and C or C′ planes also give the sense of shear. Fig. 7b illustrates the results of 15 such measurements by a tangent lineation plot, in which arrows at the pole to the C or C′ planes indicate the direction of movement of the footwall. The arrows define a coherent pattern, which indicates NE extension for the example.

6. Conclusions

The method described above allows rapid and accurate measurements of planar orientations in core that has been cut. It is commonly necessary to use such core to supplement first-pass analysis where comprehensive measurements have not been previously possible due to the requirement for timely acquisition of assay results. The method complements the use of α and β angles in whole core, reduces the risk of data loss from cutting core for sampling, and can be applied to core that is not cut exactly through the centre with negligible loss of accuracy. An Excel spreadsheet for calculating the orientation of planes from measurements of NM, NO and β, along with drill hole survey data, and instructions are available from the JSG web site.

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Appendix. Supplementary material

Supplementary material can be found, in the online version, at doi:10.1016/j.jsg.2010.04.011

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