THE USE OF CORING-INDUCED PETAL FRACTURES IN COAL TO SUPPLEMENT AND GROUND TRUTH THE INTERPRETATION OF IMAGE LOGS.

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SUMMARY

Resistivity and acoustic scanner image logs, in both the CSG and coal-mining industries, are the preferred means of determining azimuths of joints and cleat in coal. This paper indicates the need for care when interpreting cleat azimuths from image logs.

Image logs of the bore wall often exhibit large fractures (joints) that intersect the entirety of the bore wall. They are visible as sinusoidal traces. Those fractures that have low height (cleat), and intersect the bore wall in one or two places, are represented by vertical to sub-vertical linear traces on an image log. These lineations can be represented on a stereo- or polar net as a point with a plunge and trend. Both joints and cleat generally have high dips (greater than 75°).

Resistivity image logs detect both joints and cleat. Acoustic image logs often only record joints. The value of obtaining cleat, joint and horizontal stress azimuths, is in planning the optimal orientation of deviated in-seam (lateral) production wells.

An image log of a cleat lineation records the bore wall intersection azimuth (BIAZ), that is an apparent azimuth, as well as the apparent dip (or plunge) of the lineation. The best way to determine true azimuth of cleat from lineations, on an image log, is from a statistical weighted mean of numerous BIAZ measurements. In some instances, cleat azimuth has been calculated as 90° to BIAZ. Some interpreters view the dispersion of azimuths as a natural feature, when the dispersion is an artefact arising from the intersection of cleat of the same azimuth, at varying distances from the centre of a bore wall.

Petal fractures (PF) in coal, when combined with breakout information, can also be used to determine or ground truth joint/cleat azimuths of both large and small scale fractures. Bedding-plane observations of core also provides cleat/fracture information not obtainable from an image log**.**

Keywords: cleat, azimuth, interpretation, image logs.

INTRODUCTION

The Coal Seam Gas (CSG) industry routinely uses image logs to determine the azimuths of joints and cleats in coal seams. Titheridge (2014) developed an alternative method of determining cleat azimuths using the presence of coring induced tensile fractures (CITF), mainly petal fractures, and breakout on an image log. In those CSG wells, where there is no core recovered, similar fractures in the bore wall are referred to as drilling induced tensile fractures (DITF). The CITF method has provided an opportunity to compare cleat azimuth results from CITF and image logs. In several wells examined in 2008, it was found that cleat azimuth results determined by the CITF method differed from image log interpretations by a service provider, by 90°. Recent observations of similar differences (confidential company report, 2014) has prompted a review of the geometric principles of image log interpretation of cleat lineations.

BACKGROUND

The aim of CSG exploration is to obtain information that will allow planning of CSG production wells, as well as assess lateral variation in production. Successful CSG production is substantially dependant on gas content, gas saturation and permeability. This paper focusses on attributes affecting initial permeability (cf. the changes in permeability that occur during production of CSG or mine gas drainage). Initial permeability is inversely related to the magnitude of the normal stress component of the principal horizontal stresses acting on cleat (Titheridge, 2014). It is assumed initial permeability can provide a general indication of future production.

The primary determinants of permeability are the interconnectivity and spacing of joints and cleat, and the effective normal stress magnitude acting on cleat (Table 1). The latter determines cleat aperture. The normal stress magnitude acting on coal depends on the angle between the major horizontal stress azimuth (S_H) and cleat and joint azimuths. This angle may range from oblique to perpendicular. Hence a knowledge of the azimuths of cleat and joints in coal, as well as in-situ stress azimuths, is fundamental to CSG production. For a review of the influence of stress azimuth and magnitude on coal permeability the reader is referred to Bell, 2006 (and paper reviews therein), Gray and See, 2007, Titheridge, 2014 and Mukherjee et al., 2017.

In this paper the term "joint" refers to planar Mode 1 extension joints that intersect the entirety of the bore wall. A joint is represented by a sinusoidal trace on an image log. The term "cleat" refers to smaller scale features, that intersect one or both sides of the bore wall that are represented by lineations on an image log (Figures 1 and 2). These are definitions of simplicity and convenience for this paper (cf Laubach et al., 1998; Dawson and Esterle, 2010). Image logs used to determine joint/cleat and breakout azimuths, are of three types – resistivity , acoustic and optical. With regard to vertical drill holes, each type has advantages (detail of structures) and disadvantages (cost, limitations in application). Optical image logs provide the best definition of structural and sedimentary features and are relatively cheap. However they require clean water (no turbidity), and cannot be used where there is an issue with bore wall stability. They are well suited to shallow wells and up-hole in underground mines. Logs used for CSG are mostly resistivity. They are expensive but provide good definition, particularly of the smaller scale cleat. Logs used in coal mine exploration are mainly acoustic.

Table 1. Factors affecting initial* permeability of coal

Major factors 1. Cleat/joint interconnectivity Height ↔length ↔ spacing Number of cleat generations (i). Primary face cleat only (compression) (ii). Face and butt cleat (compression and extension/uplift) (iii). Multiple cleat azimuths (generally associated with folding) 2. Fault stress regime and magnitudes **reverse:** S_h is vertical - high stress acting on vertical cleat **normal, strike slip:** S_h horizontal - low stress acting on cleat	3. Angle between S_h/S_H and face cleat **S_h ⊥ FC** **90°≥ (∠S_H ^ FC) ≥ 0°** **S_H ⊥ FC** **high** ↔ **intermediate** ↔ **low** (determines magnitude of normal stress acting on cleat) **Other factors** 3. Mineralisation of cleat 4. High CO2 (% and content; coal mining and CMM) - causes swelling ******before matrix shrinkage associated with production/desorption*

AZIMUTHS OF JOINT PLANES AND CLEAT LINEATIONS FROM IMAGE LOGS AND CORE

Joint plane azimuths from measurements of the properties of a sinusoidal trace

Joints with a dip of less than 90° intersect the entirety of a bore wall if they are of sufficient height. They are represented by a sinusoidal trace on an image log. The azimuth of the minima of the sinusoidal trace is the direction of dip. This can be represented by a lineation on a stereonet or polar net (with a plunge and trend). The strike of the joint is orthogonal to dip azimuth (Figure 1). Determination of joint azimuths comprises individual measurements of single fractures. Most fractures recorded in image logs from vertical drill-holes have a dip of 80-90 degrees. For the purposes of discernible separation of very similar apparent dips on a stereo- or polar net, and for explanation of principles in this and subsequent sections, E-W strikes with a dip of 70 degrees are used for both planes and lineations.

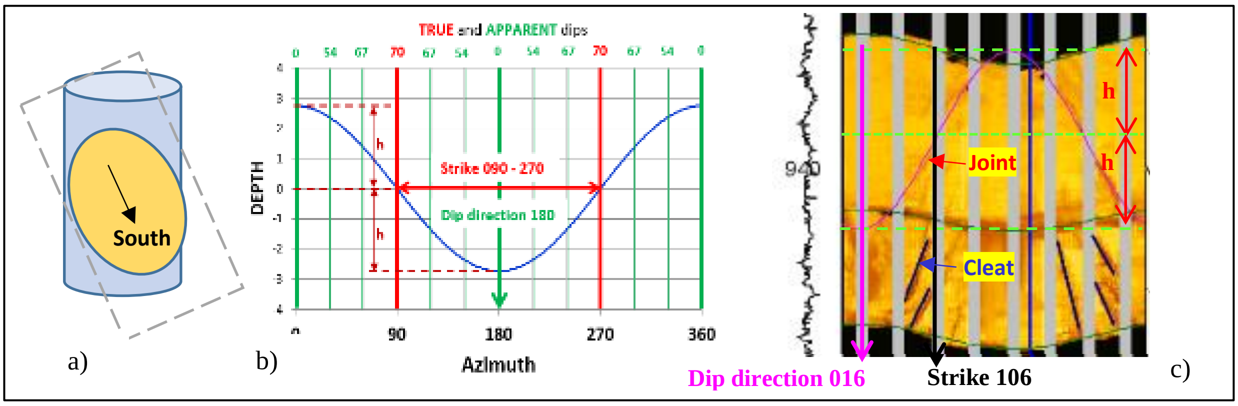


Figure 1. Representations of a planar joint. a) diagrammatic section of borewall cylinder with joint dipping to South; b) schematic of sinusoidal trace of dipping plane on a rolled-out cylinder wall. The strike is 090/270. The dip direction is 180. Note the maximum and true dip (70°) is coincident with the mid-point of half the height of the blue sinusoid. At this depth (0 metres), the inclined plane passes through the centre of the bore wall. c) Image log of an interpreted joint (top) in coal. The smaller scale cleats (at the base of the image) have similar dips at the same BIAZ as the overlying joint, indicating the smaller scale cleat have a similar azimuth to the larger scale joint.

CLEAT AZIMUTH FROM STATISTICAL INTERPRETATION OF LINEATIONS FROM THE MEAN OF BOREHOLE INTERSECTION AZIMUTHS (BIAZ): METHOD 1.

Smaller scale cleat may intersect the bore wall on one or two sides of the bore wall. As these features have limited height they do not intersect the bore wall in the up-dip or down-dip part of the hole and appear as planar lineations on an image log (Figures 1c, 2b,c).

In most situations, cleat on an image log records an apparent azimuth (BIAZ) with an apparent dip or plunge. The true azimuth is associated with the largest number of cleats in a designated azimuth class (generally 10 degrees) intersecting the bore wall (Figure 3). This class is also associated with the highest apparent dips. The only instance where the BIAZ is the true strike is where the cleat (or its extrapolation) passes through the centre of the bore-hole; this BIAZ is also coincident with the true (maximum) dip (Figure 3).

As most of the BIAZ of cleat are apparent azimuths, then one or several individual BIAZ are insufficient to determine cleat azimuth.

As an approximate rule of thumb, at least 20 BIAZ within a 50 degree range are required to determine the mean cleat azimuth. In most cases, cleat BIAZ are conveniently presented as a rose diagram or a histogram (Figure 4). A weighted mean of the numbers of the BIAZ in the vicinity of a maxima will provide a close measure of the true azimuth.

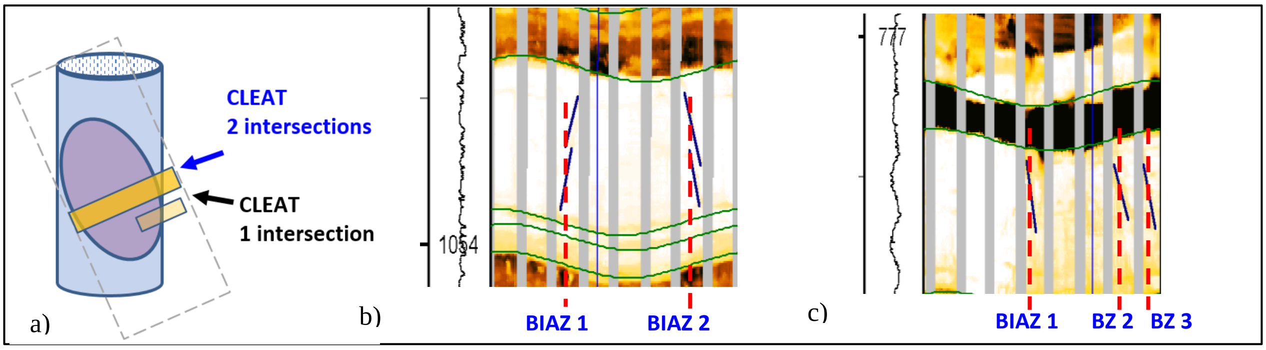


Figure 2. Fractures (cleat) that do not intersect entirety of the bore wall and their appearance on a scanner image. a) Diagram of two cleats, one enters the bore wall on one side, the other passes through the entirety of the bore wall. Both have limited height and as a result do not intersect the bore wall in the up-dip or down-dip part of the hole. b) Two (paired) cleats, same depth with opposite dip. Strike = ((BIAZ1 + BIAZ2)/2) ± 90. In addition to direct calculation, these lineations can be counted in a statistical population. c) Unpaired single cleats that can only be analysed as part of a statistical population.

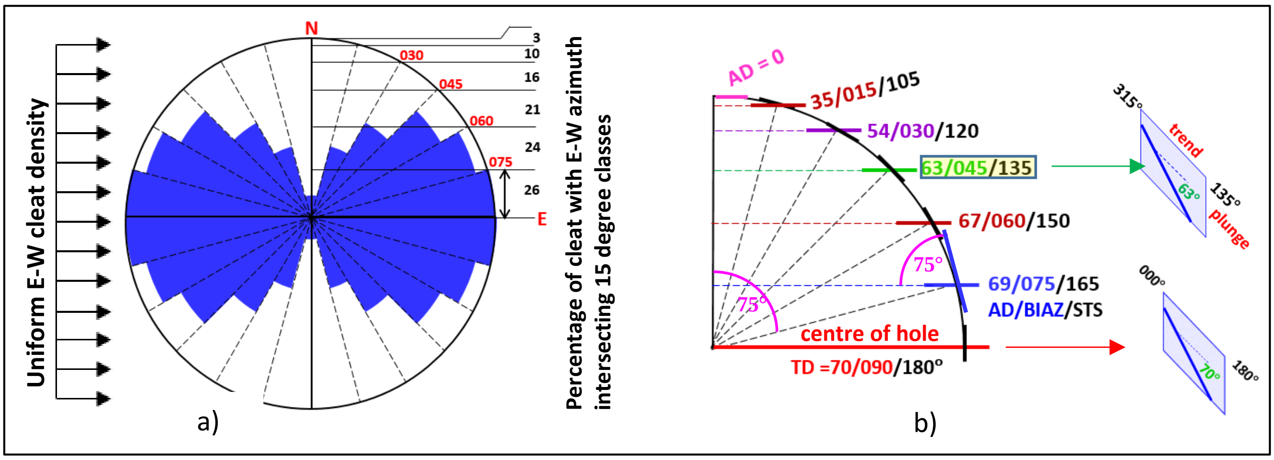


Figure 3. Rose diagram of 15 degree increments that results from a plot of the bore wall intersection azimuths (BIAZ) of one uniformly oriented E-W cleat set that dips 70° South a) Note the relative percentage within each 15° class interval (3-26%). If the data was plotted at intervals of one degree, the highest number of cleat azimuths intersecting the bore wall would occur at 090. This azimuth would also exhibit the cleat with the true (highest apparent) dip. b) The E-W trending green cleat (highlighted in light yellow) has an apparent dip (AD/plunge) of 63 degrees, it intersects the bore wall at 045 (BIAZ), and the strike of the section tangential to the bore wall (STS/trend), is 045+90=135. The STS or trend of the cleat lineation that passes through the centre of the hole is 0/180.

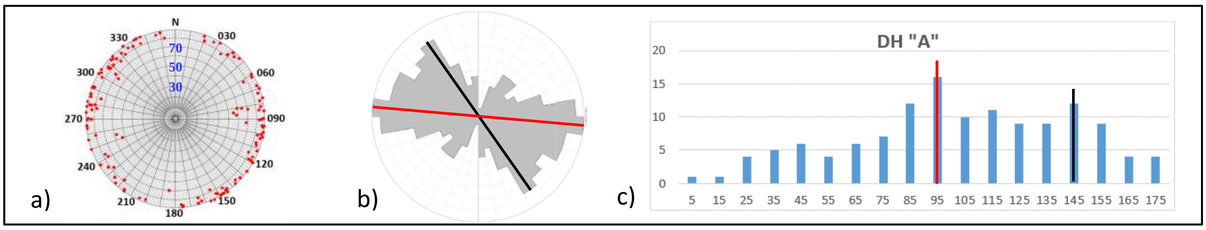


Figure 4. Method 1: Cleat azimuths based on number of BIAZ in 10° classes for DH "A". a) Polar plot of BIAZ and apparent dips (10 degree classes). Highest apparent dips (or lowest tilt angle) are closest to the graph perimeter. b) Rose diagram (number of BIAZ) in diametrically opposite 10 degree classes in "a" that have been added or averaged. c) Histogram with the same maxima as in "b". Cleat azimuth maxima (095, 145, n =129). DH "A" is described in more detail below and illustrated in Figures 8 and 9.

TRANSFER OF IMAGE LOG BIAZ DATA TO A STEREONET TO DETERMINE STRIKE

Bore walls are circular sections and therefore the strike of the section on a bore wall is tangential to the bore wall at the point where a cleat intersects the bore wall. Where, for example, the BIAZ of a cleat is 045, the strike of the (tangential) section (STS or trend) is (045+90=) 135. The plane containing two or more apparent dips on a stereo-net defines the true dip and strike. To obtain strike and true dip from image log data, it is necessary to rotate the line containing the BIAZ and apparent dip by 90 degrees so that the STS (= trend of lineation) is correctly represented on the stereo-net (Figures 5 and 6). If this is done for two or more lineations intersecting the bore wall, at different distances from the centre of the bore, and with the same strike, the lineations will define a great circle on the stereo-net. The process, illustrated in Figure 5, demonstrates that a wide range of BIAZ can be a result of many cleats with the same azimuth intersecting the bore wall at different distances from the bore wall centre.

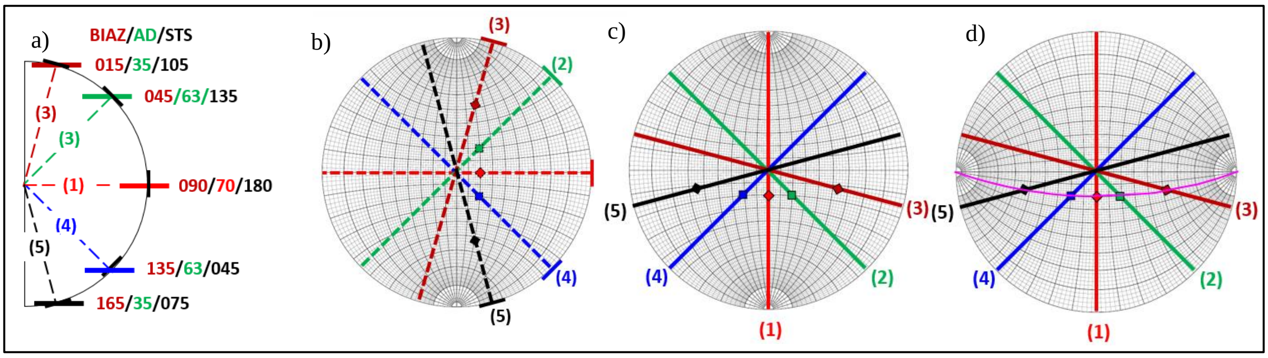


Figure 5. Rotations of apparent dip (AD) and strike of lineation to determine true dip 70°S and strike of a plane (090/270). a) 5 cleats with E-W strike and dip of 70°S, and variously labelled 1 to 5. Cleat 1 passes through the centre of the core with an azimuth of 090. The other cleats also have an azimuth of 090 but the BIAZ changes away from the centre of the core. b) the plunge of Cleat 1 (70°) can be plotted on the oriented on the E-W diametral plane. To plot the plunge of Cleat 2, the line is rotated to the E-W diametral plane, the plunge plotted, and line restored to 045. The same process is applied to Cleats 3, 4 and 5. c) Cleat 1 (BIAZ 090) is then rotated to the STS (trend) of 180 (90+90); see Figures 3a,b where the STS (is 0/180). Similar is done for Cleats 2, 3, 4, and 5. d) The stereo-net is then rotated so that all the apparent dips fit a great circle on the stereo-net. The five apparent dips (plunges), of cleats 1 to 5, define the plane that strikes E-W and dips 70°S. Any two apparent dips will define true dip and strike.

ALTERNATIVE METHOD OF DETERMINING THE AZIMUTH OF CLEAT LINEATIONS: METHOD 2.

Some unpublished interpreted image log diagrams that have been generated by software and provided to the CBM industry, indicate a different method has been used to determine the azimuths of cleat represented by lineations on an image log. The method is not described in the reporting of interpretation but it has been possible to deduce the underlying rationale and process from the fortuitous inclusion of a polar plot with a single joint and a single cleat (described subsequent section).

Figure 6 shows a hypothetical dipping plane on an image log (70°S/090), and the determination of cleat azimuth via Methods 1 and 2. The results from both methods have an exact difference of 90°. The determination of cleat azimuth via Method 2 is similar to the determination of the strike of a plane, whereby the azimuth of a plane is orthogonal to the direction of dip (lineation trend).

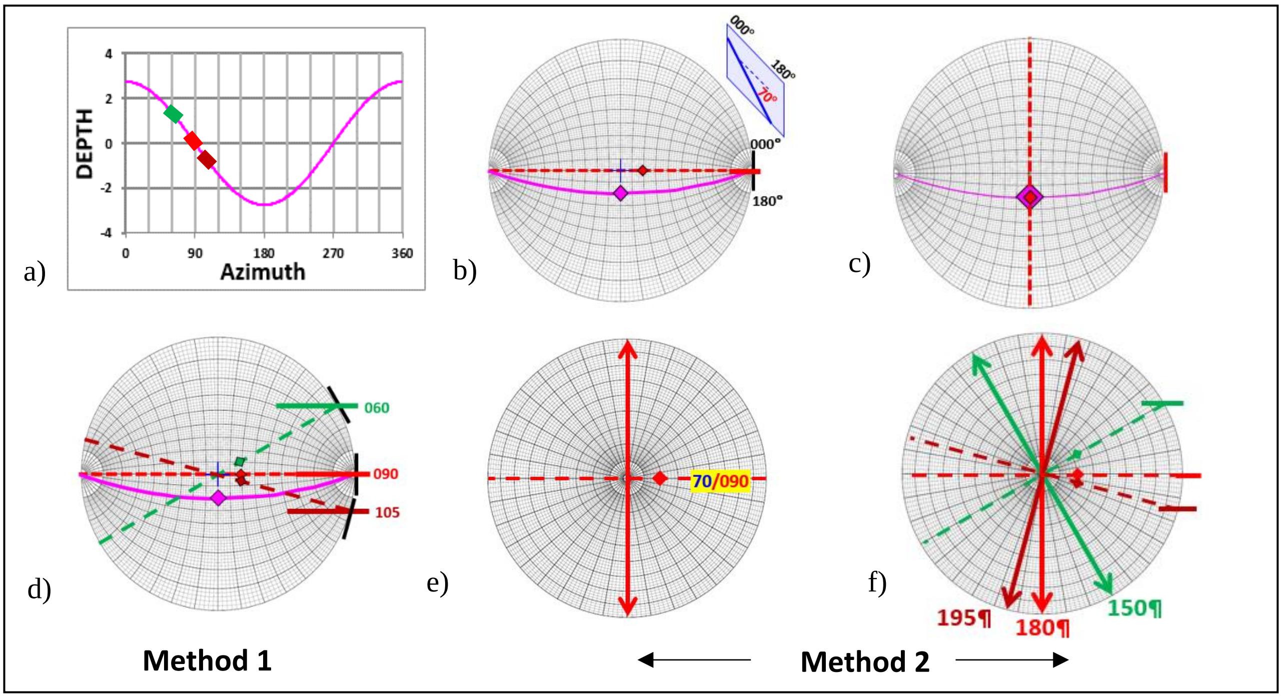


Figure 6. Comparison of Method 1 and Method 2. a) "Image log" E-W joint (pink sinusoid), dip 70°S. Cleats (red, green, brown), with BIAZ of 090, 060, and 105. Red cleat (090) passes through centre of bore hole. Brown and green cleats (060,105) do not pass through centre of hole. b) Joint on stereo-net, true dip lineation (plunge). E-W cleat lineation with 70° plunge to E. c) Rotation of cleat to N-S to represent actual plunge. **Note the coincidence of joint and cleat dip lineation.** d) Determination of cleat azimuth by **Method 1** involves statistical analysis of BIAZ data (060, 090,105). The cleat with an azimuth of 090 passes through the centre of the core and therefore it must have the same strike as the plane that contains it (sinusoidal trace of "a"). e) **Method 2.** The

azimuth of the red cleat is taken to be orthogonal to cleat lineation that plunges 70° to 090 (double arrow). f) The azimuths of cleats with BIAZ of 060 and 105 are also rotated by 90°.

DETERMINATION OF CLEAT AND JOINT AZIMUTHS FROM CORE

Examples of petal fractures and their relationship to horizontal stress in core and the bore wall are illustrated in Figure 7. Determination of cleat/joint azimuths from core involves measurement of the angle between a cleat, and the apex of a coring induced petal fracture on the bore wall. The basis of cleat azimuth determination is that the strike of a petal fracture has the same azimuth as S_H, and the apex of the trace of a petal fracture has the same azimuth as breakout on an image log. Cleat azimuth can be determined by measuring the angle between cleat/joints and the apex of a petal fracture (formed at the intersection of a petal fracture and the core circumference). Details of the method of calculation of cleat azimuth using petal fractures are illustrated in Titheridge, 2014.

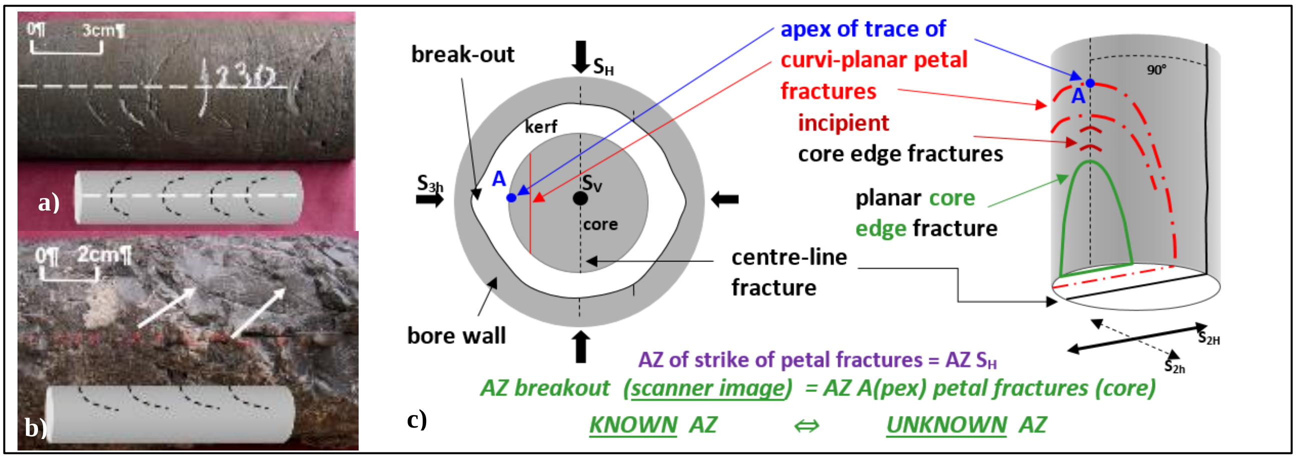


Figure 7. Coring induced petal fractures in core and the borewall, and their relationship to horizontal stress and breakout azimuths. a) and b) Top and side view of petal fractures in core. c) Fracture/stress relationships in core and associated bore wall.

Overview and comparison of joint/cleat azimuths from image logs and the CITF method, in a CBM lease, Queensland

In 2007/08 image logs were used to obtain cleat azimuths from four wells (DH's "A","B", "C" and "D") from a CBM lease. In addition, cleat azimuths were obtained using the presence of coring induced petal fractures (method outlined above, details Titheridge, 2014). The results are presented in Figure 8, with the results via the CITF method overlain on the image log results.

The numbers of azimuth determinations via the CITF method is low as at least half the coal core had been removed for gas desorption and destructive testing (proximate and petrographic analyses) prior to applying the CITF method. It is estimated that as many as three to four times as many cleat azimuth determinations could have been obtained had the measurements been made whilst the coal was still in the splits, or, the core marked to preserve orientations of adjacent pieces of core.

Regardless of the handicap outlined above, a comparison of the image log interpretations of Methods 1 and 2, and the CITF method was made (Figure 8). In Holes "A" and "B", the major azimuths from the CITF method were approximately orthogonal to the image log results. The results from Holes A and B prompted enquiry with the provider of the image log interpretation. In the final hole to be drilled in the series, Hole "D", the results from both the Method 1 image log interpretation and the CITF method (Figure 8) were nearly identical. This prompted enquiry as to how the differences arose in Holes "A" and "B".

A COMPARISON OF METHODS TO OBTAIN AZIMUTHS FROM CLEAT LINEATIONS

The cleat azimuths determined by Method 2 for Holes "A" and "B" indicate the fractures are perpendicular to S_H (Figure 8) and suggest an unfavourable stress/fracture azimuth scenario for permeability (Table 1). It is noteworthy that if the image log azimuths for cleat lineations (BIAZ) for Holes "A" and "B" are rotated by 90°, there is a reasonable fit between the azimuths of both the Method 1 image log interpretation and the CITF method (Figure 9a). This is also a more favourable stress/fracture azimuth scenario for permeability.

Conversely if the same rotation of cleat lineation BIAZ (Method 2) is applied to Hole "D" (determined by Method 1 and the CIF method), then the cleat will be perpendicular to the joint azimuths, determined from a sinusoidal trace (middle rose diagram of Figure 9b). Observations of core do not support this, and it (generally) does not make geological sense for the larger scale joints to be nearly orthogonal to the cleat represented on the image logs by lineations. This is supported by core observations where there is clearly only one cleat and one joint azimuth that are very similar.

Representation of structural data with tadpole plots of both planes and lineations.

Tadpole plots graphically record both dip and azimuth of specific structures, and their depths. In addition to the graphic tadpole plots, some logs also record the same information in numerical form. The y-axis of the tadpole plots is depth, the x-axis records **dip** of planar joints that intersect the entirety of the bore wall with a sinusoidal trace, as well as the **apparent dip** of cleat lineations (LHS Figure

10). The tail of the tadpole is effectively a "z" axis that records **true dip azimuth** of planar structures and the **BIAZ** of lineations (Table 2).

Table 2. The relationship between dip log tadpoles and strike azimuths of planes and lineation trends and analysis

Fracture/Form	Intersection of fracture with bore wall	Tadpole tail information	Numerical format of tadpole information	Obtaining Strike AZ
Joint plane/ Sinusoid*	Entirety	Dip direction(trend) Orthogonal to strike	True dip/true dip AZ	Orthogonal to true dip
Cleat/Lineation	Side (**Method 1**)	Plunge trend; Orthogonal to BIAZ	Plunge/BIAZ	**Mean of BIAZ**
	Side (**Method 2**)			**Mean of orthogonal to BIAZ**

* Includes bedding, joints, faults and cross bedding.

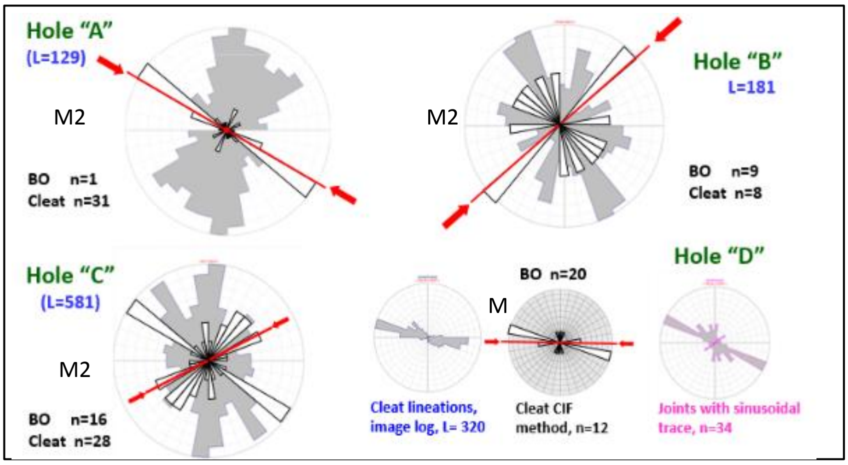


Figure 8. Cleat azimuths determined by image log Methods 1 and 2, and the CIF method.

Cleat azimuths for holes A, B and C were determined by Method 2 (grey).

Cleat azimuths for Hole D were determined by Method 1 (grey).

The azimuths from the CITF method have black borders around a white centre. Maximum horizontal stress azimuths determined from breakout are indicated by red lines and arrows.

L=cleat lineations . BO = breakout.

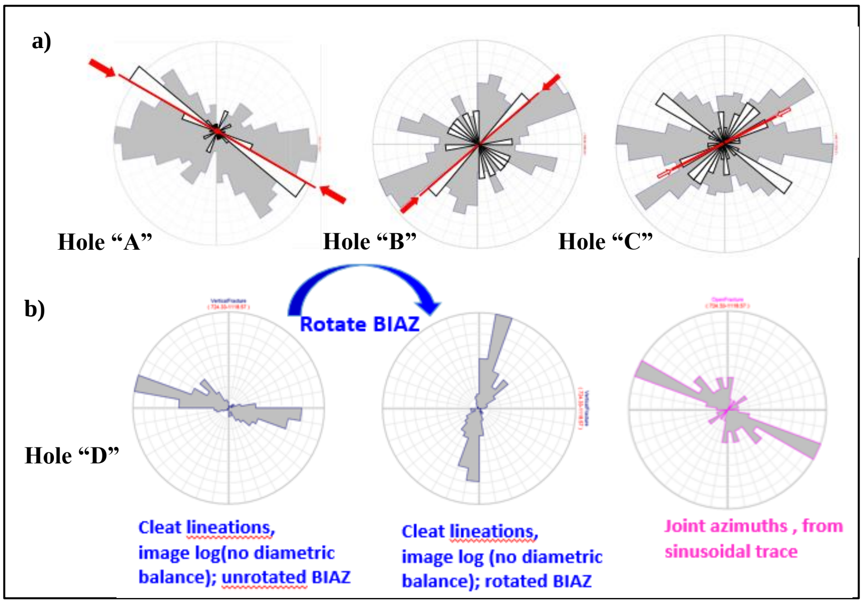


Figure 9. Rotation of cleat azimuths by 90 degrees.

a) Holes "A", "B: and "C" based on use of Method 2 after (restorative) 90° rotation of image log cleat azimuths .This results in a good match with cleat azimuth determined by the CITF method for Holes "A" and "B".

b) Hole "D" based on use of Method 1 after rotation of lineations ofcleat BIAZ by 90° (middle). The rotated cleat azimuth does not match the larger scale joint azimuths determined from their sinusoidal traces (RHS).

AZIMUTHS FROM JOINTS AND CLEAT IN CLOSE PROXIMITY: METHODS 1 AND 2

In Hole "D" numerous inclined joints (top inset LHS Figure 10), are present from 789 to 799m. The height of the planar joint indicated by the interpreted pink sinusoidal trace is about 80cm. This joint has a dip and strike of 75/125 (see bottom LHS expanded inset). A cleat lineation "A", with a BIAZ of 117 is in close proximity to another lineation "B". The sinusoidal trace is based on fitting a curve to lineations "B" and "C". These data are plotted on a series of polar plots (a to c) in Figure 10 (RHS).

The RHS of Figure 10 illustrates a polar net analysis to test the results of applying Method 1 vs Method 2 to the joint and cleat "A" that are in close proximity. In Figure 10a (Method 1A), the procedure consists of plotting the strike of the joint and the BIAZ of cleat "A". Although the azimuth of the plane and the trend of the lineation are discordant, the strike of both is essentially the same with a difference of 8 degrees. In Figure 10b (Method 1B), the lineation is rotated 90° to the strike of the tangential section (STS) of the lineation of 027. This is the true trend. The process of rotation makes the dip and trend lineation of the plane and the cleat almost identical (refer back to Figure 6c). If Method 2 (Figure 10c) is used, and the interpreted strike is drawn perpendicular to the dip and trend of the lineation, then the difference between the strike of the plane and the cleat, is stark. Similarly there is disagreement between the trend and plunge of the dip lineations. Whilst Methods 1A and 1B have identical azimuth results, it is only Method 1B that has identical results for both trend and plunge of the lineations. Method 1, along with statistical analysis is therefore the preferred method of the authors to determine azimuth of cleats.

In the inset in the bottom right of Figure 10, some image log snapshots from Hole "E" (Bowen Basin) are presented in Figures 10 d,e,f,g, and h. The observations from the image log report of Hole "E" are fundamental to understanding the process of Method 2. Figure 10d illustrates the sinusoidal trace of a joint (blue green) with a cleat in close proximity (circled white and enlarged in Figure 10e). Their dips on the image log are very similar. In Hole "E" joint and cleat details (azimuth and dip/plunge) for each 2m interval were presented. In most figures there was an abundance of data in which it was not possible to identify individual joint and cleat details (Figure 10f). This was because of the large amount of data plotted over a range of 0-90 degrees, where the range of dip/plunge was greater than 50°, and mostly greater than 80°. In the example illustrated in Figures 10g,h there were only two structures in the 2m summary interval (the joint and cleat of Figures 10d,e). The polar net figures (10g,h) shows a joint that strikes approximately N-S, with an adjacent cleat with similar dip striking nearly E-W. The interpretation of the E-W cleat azimuth emanates from Method 2. By applying Method 1, the authors' interpretation of the same cleat azimuth is approximately N-S (red line of Figure 10h) and similar to the strike of the joint; this is consistent with application of Method 1 applied to Hole "D" (Figures 10a,b).

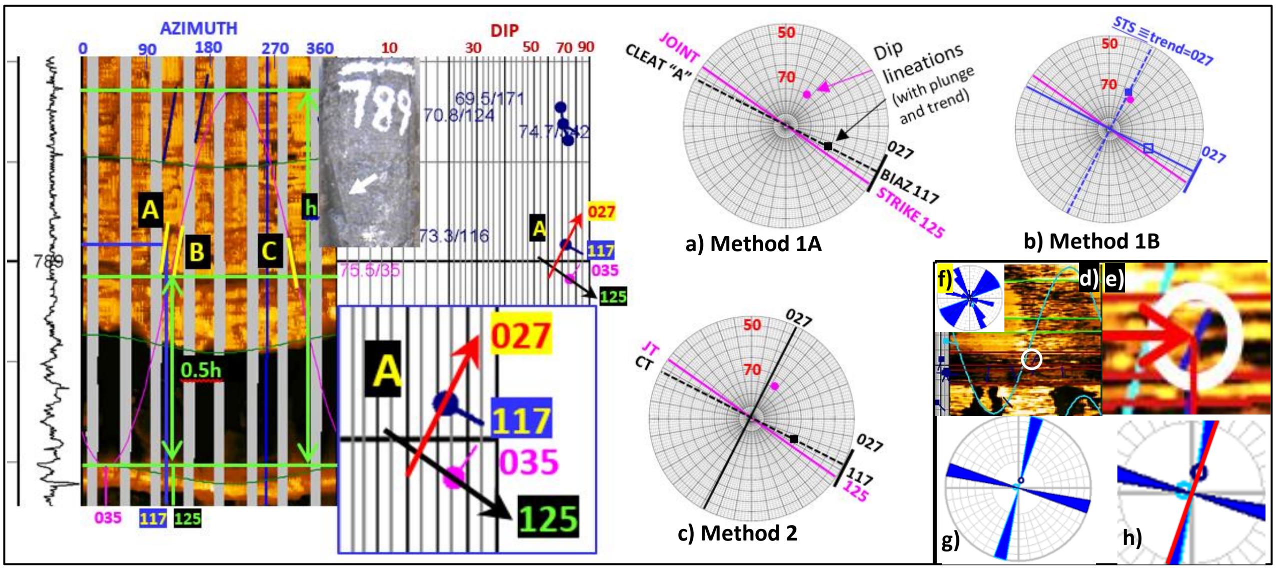


Figure 10. Application of Methods 1 and 2 applied to drillholes "D" and "E".

Recognizing whether Method 1 or Method 2 has been used to determine cleat azimuths.

The indicators include: 1) a comparison of whether or not the polar net BIAZ/dip plot matches the rose diagram or histogram (Figure 4). If there are one or two cleat azimuth classes, this should be easy (Figures 11a,b), but if there are multiple azimuth classes, distinction may be difficult (Figures 11c,d); or 2) an independent means of measurement (eg CITF method of Titheridge, 2014; mechanical orientation of core).

INTERPRETATION OF THE DISPERSION OF CLEAT AZIMUTHS BASED ON LINEATIONS.

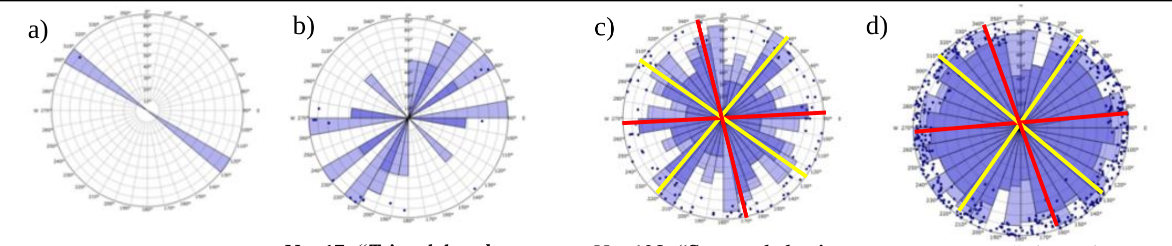
Figure 3 that illustrates the hypothetical model of lineations associated with a known single E-W azimuth. Figure 11 (below) shows examples with considerable variation in the number of lineations (one to hundreds), and the number of azimuths (one to six). In Figure 11, lineations (recorded as dots on polar plots) appear to be treated as measured individual azimuths (as is the case for joints), rather than dispersion of one or several populations. This is indicated by the wording of automated interpretations (italicized).

The interpretations of Figure 11 are debatable. Figure 11a is based on one lineation. With reference to Figure 3, it is estimated there is only about a 15% chance that the single lineation is within the 10 degree azimuth class that contains the (true) strike. Figure 11b is described as having a trimodal distribution. There are insufficient measurements to be certain this is correct. It is easily possible there are only one or two azimuths. If lineations on an image log are sparse, inspection of core, or the use of the CITF azimuth method, could resolve the modality and the true azimuths. Figure 11c, describes the distribution as "scattered". Three modes are cited in Figure 11c. There is probably a fourth (~ 087). Within each of the azimuth classes, the range of azimuths is probably narrow rather than scattered; the "scatter" (dispersion) is an artefact of most fractures not passing near the centre of the bore wall (see Figure 3). In Figure 11d, the "scattered" distribution is more likely to be due to the presence of four distinct azimuths, each with a narrow range; again, inspection of core could easily resolve this.

The influence of stress and folding on cleat azimuth distribution on an image log.
Figure 3 illustrates a theoretical distribution of E-W stress azimuths. In the event SH is E-W and the ratio of S_H:S_h is high, stress concentration in the N-S quadrants as a result of a high E-W directed compression, could render cleat invisible and reduce the dispersion

of azimuths. The low angle of incidence of cleat to the bore wall might also be a factor in image visibility.

At one extreme, a single cleat azimuth may reflect compression and subsidence with little or no subsequent uplift; eg DH "D" Figures 8 and 9). Many orthogonal sets reflect compression and uplift. In Figures 11c,d, the yellow orthogonal set is interpreted to be a result of compression followed by uplift. The two red sets are interpreted as cross joints associated with folding. Clearly interpretation of joints and cleat would benefit from synthesis with regional and local seismic and field mapping. Of more immediate connection with interpretation of image log data from individual drill-holes, are the benefits of details that can be obtained from the bedding plane of coal core – cleat angles, intersections – cross-cutting vs abutting, and mineralisation – species, preferred azimuth.



N= 1. "Dominant coal fractures strike 125"

N = 17. "Trimodal coal fractures strike towards 035, 055 , 085"

N = 106. "Scattered, dominant coal fractures strike towards 035, sub dominant 130, 175"

N = 393. "The coal fractures strike distribution is scattered"

Figure 11. Examples of the pattern of the distribution of Borehole Intersection Azimuths (BIAZ) with numbers of data ranging from 1 to 393. Authors' interpretations of azimuth in c) and d) indicated by yellow and red lines.

CONCLUSIONS

The intersection of cleat on one side of the bore wall produces a dipping lineation. The bore wall intersection azimuth (BIAZ) is an apparent strike and is associated with an apparent dip. The strike of the tangential section (STS) at the BIAZ contains the true trend and plunge of the lineation. This must be accommodated in plotting cleat lineations from image log data on a stereo- or polar-net.

In the authors' opinion, the best way to determine true azimuths of cleat lineations from an image log is from a statistical weighted mean of numerous bore-hole intersection azimuths (BIAZ; Method 1). In Method 2 a 90° rotation of bore-hole intersection azimuths (BIAZ) appears to be software procedure. In effect, the apparent dip of a lineation has been treated as if it were the plunge trend of the dip of a joint. Differences in interpretation of cleat azimuths of 90° between Methods 1 and 2 is likely to have implications for planning the azimuths for in-seam production wells, and ultimately gas production. To convert Method 2 to Method 1 results, there is a simple remedy – rotate the BIAZ cleat lineation azimuths (another) 90°.

In the absence of documentation of the method of cleat azimuth determination by service providers, the end users (geologists, production engineers) need to verify the method used. The value of inspecting core to supplement image logs cannot be over-emphasized. The results of application of the CITF method has prompted a closer examination of the interpretation of cleat azimuths from lineations on image logs and provided the impetus for this paper. Petal fractures (PF) in coal, when combined with breakout information, provide a means to ground truth the results of both acoustic and resistivity image log analyses.

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