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AN ANALYSIS OF FRACTURING IN HOLE UG-2
SPENT FUEL TEST-CLIMAX

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JUNE 1984

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by

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ABSTRACT

Detailed fracture logging and analysis of the UG-2 core from the Climax Stock is reported. This borehole is about 183 m long (600 ft) and slants downward below the Spent Fuel Test workings, thus representing the only sampling of the quartz monzonite at depth. An effective means of orienting the core sections relative to a certain joint set of known orientation is demonstrated, and a computational procedure for accomplishing this in non-vertical boreholes is presented. Although this core orienting scheme is approximate, modal joint set orientations could be estimated. A distinctive low-angle joint set which pervades the existing workings is the most frequently encountered set at depth, and its spacing distribution is shown to be negative exponential. The next most common joint set in the core strikes northeasterly and dips steeply to the southeast. Another set strikes northwesterly and is nearly vertical. These groupings generally agree with results of previous surveys in the area, which suggests the rock mass is homogeneous in terms of its joint pattern.

1. INTRODUCTION

1.1 Purpose and Scope

The Spent Fuel Test-Climax (SFT-C) is being conducted under the technical direction of the Lawrence Livermore National Laboratory as part of the U.S. Department of Energy's Nevada Nuclear Waste Storage Investigations. One of the tasks of the SFT-C has been to characterize the fracture system in the Climax Stock (Fig. 1) for hydrologic and rock mechanics purposes. To accomplish this, underground fracture mapping [1,2] and core logging of joints [3] has been conducted. This work has produced a large amount of data representing several thousand joints. Because of its size, this data base is difficult to incorporate and interpret within a single report. The purpose here is to present and summarize part of the data, which pertain to a specific borehole, UG-2. Extensive fracture data were collected from this hole because of its location and potential use for hydrofracturing stress measurements. Conclusions presented here focus mainly on the data at hand; a more comprehensive interpretation of the structural geology of the Climax Stock, which will include these observations, is in preparation [4].

Fig. 1. Geology of the Climax Stock.

This report focuses on the following topics:

- . Description of major geologic discontinuities
- . Joint orientation statistics
- . Joint spacing statistics.

These are discussed in the context of whether the joints were open or closed (healed) in the core and the types of mineralization observed. Throughout the report, the term "fracture" includes any discontinuity having little or no tensile strength, such as a joint, weakness zone, or fault. The term "joint" specifically connotes a break of geologic origin along which there has been no visible displacement [5].

1.2 Hole Description

UG-2 is one of four NX size exploratory holes drilled from the Piledriver workings prior to construction of the SFT-C (Fig. 2). Figure 3 shows the locations and orientations of all four holes, and further details of the drilling procedure and downhole directional surveying may be found elsewhere [3]. The other three holes were nearly horizontal and thus provided information at the same elevation and in the vicinity of the proposed facility. UG-2, on the other hand, extends downward at an inclination of 60 degrees to a depth of over 150 m (500 ft) below the workings. Because this represents the deepest penetration and sampling of the quartz monzonite portion of the Climax Stock to date, a more detailed form of logging was warranted.

As indicated by Fig. 3, UG-2 was drilled in two stages. The first length of about 122 m (400 ft) was completed prior to construction of the SFT-C in 1978, at which time a simple exploration log of the core was prepared [3]. Several years later, the hole was extended to its final length of 183 m (602 ft), and the more detailed information contained in this report was derived from the entire core.

Fig. 2. Piledriver and SFT-C facilities.

Fig. 3. SFT-C exploratory hole locations and orientations.

2. CORE LOGGING AND ORIENTATION PROCEDURE

2.1 Logging Procedure

Within the quartz monzonite, the rock shows little or no lithologic variation, except for isolated dikes, inclusions, and localized alteration along jointing. Consequently, the detailed logging of UG-2 emphasized fracture characteristics, including location, orientation, mineralization, and alteration. For the UG-2 extension, this information was systematically recorded in the form shown by Fig. 4. Included on the left are columns for the core depth, the number of the drill run, and the Rock Quality Designation (RQD = percent recovery of core greater than 10 cm length for each 1.5 m run). A sketch of the core, showing apparent dips of joints, was provided at a length scale of 1:40 in the next column. The depths of planar features were recorded as the point where they intersected the centerline of the core (i.e., the core axis). The relative orientation is given by two angles, alpha and beta, which are defined below. The last section of the log includes descriptive information about the discontinuities, such as infilling thickness, type of mineralization and alteration color, surface planarity, slickensiding, and whether they were open or healed in the core.

This method produced an effective visual record of the core; however, a more rapid system, which dispensed with the core sketch, was used for the detailed relogging of the original 122 m (400 ft) of the hole. The main objective here was to compile statistical data, so a simple tabular format was used (Fig. 5). This reduced logging time by about a factor of three.

The key element in the logging process was reconstructing the core. This was done by removing about 3 m (10 ft) of core from a storage box and piecing the sections tightly together in a single line. A section of angle stock was used as a core trough for this. Once the length was reconstructed, a tape measure was laid along this section for depth measurements of the features. The absolute depth of a core section often was uncertain, however, because a stub of core usually remained at the bottom of the hole at the end of a run. Therefore, the depth recorded during logging was referenced to a specific point marked on the core section, usually the top or bottom. In this manner, the

logged depth of a feature could be correlated with its absolute hole depth in the event further downhole surveying, such as television or televiwer, were to be conducted.

2.2 Core Orientation

As described by Wilder, et al. [3], the core was oriented in an approximate manner relative to a particular joint set in the rock mass. This method, which is also discussed by Goodman [6], is based on the presumption that the selected set has a more or less constant orientation throughout the borehole. This is apparently the case for a nearly horizontal (low-angle) set of joints in the Climax Stock, which is distinguished by characteristic wall rock alteration and quartz, pyrite, and/or sericite mineralization on the joint surfaces.

Previous underground mapping [1,2] has shown this joint set to be pervasive, with a mean fracture frequency of at least one per meter. Its modal orientation is approximately N44°W/20°NE [2]. For the present purpose, this was taken as the reference orientation for all such joints in the core. The absolute orientation of any particular core segment, which is derived from different samples of this set, is therefore only as precise as the dispersion of joint orientations about this mode. A stereonet plot of joint poles shows this dispersion to be about ten degrees in any direction [1], based on the outline of the one percent contour interval.

To perform the core orientation by this method, the low-angle joints were first identified in a reconstructed section of core. Because of the non-vertical orientation of UG-2, these intersected the core at an angle between 50 and 60 degrees. As illustrated in Fig. 6, the lower-most trace of each of these was marked, and an orientation reference line was scribed down the core through the points. The relative orientation of any other joint then could be determined by measuring the β -angle (Fig. 6) with a 360 degree graduated band wrapped around the core from the reference line. Angle α is measured between the core axis and each fracture plane. This convention and terminology was developed by Rosengren [7], and has been used widely in the field [8,9].

Fig. 6. Convention for measuring relative orientations of fractures for UC-2 core (from refs. 5 and 6).

2.3 Conversion of Borehole Orientations.

Instructions for converting the relative orientation angles to absolute (global) orientation by means of stereographic projection are given by Goodman [6]. Figure 7 is a combined upper and lower hemisphere stereonet which diagrams the procedure for UG-2. The plane labeled "L" indicates the modal orientation for the low-angle joints, and the β -plane represents a plane perpendicular to the core axis. Solid points and lines are lower hemisphere projections, while dashed lines and open dots correspond to upper hemisphere projections. (Plotting both upper and lower hemisphere points on the same stereonet may seem burdensome; however, it actually simplifies determining the angular relationship between two vectors directed upward and downward.)

The intersection of a fracture plane and the surface of a core forms an ellipse. The minor axis of such an ellipse for the low-angle joint set is defined by the two points where the β - and L-planes intersect, as labeled in Fig. 7a. Two points representing the major axis of the ellipse are then found by measuring 90 degrees in either direction along the L-plane great circle. Once these are located, as shown in Fig. 7a, we must determine which refers to the lowermost, or downhole direction because the reference line on the core (Fig. 6) passes through it. (For a vertical borehole, this point would simply be that which plots in the lower hemisphere. However, when a hole such as UG-2 is inclined, this may not be the case.) To find the downhole major axis, we draw the great circle of the plane that contains both of the major axis points for the L-plane and the axis of the borehole, as shown in Fig. 7b. (For clarity, the L-plane great circle has been removed in Fig. 7b.) Measuring along this great circle, the downhole axis is the β -plane intersection point closer to the downhole direction. The intersection between the reference line and the β -plane, which is the $\beta = 0$ degree position, is simply the intersection point between the two planes that is closest to the downhole major axis. Fig. 7b shows that this point is located in the upper hemisphere.

Fig. 7a. Stereographic projection of UG-2 axis, modal plane of low-angle joint set, and the beta plane.

Fig. 7b. Determination of the core reference line's location on the beta plane.

Fig. 7c. Example of determining true orientation of an arbitrary joint, given the alpha and beta angles.

With the reference line location along the β -plane established, the pole to any other joint plane can be plotted on the stereonet. Fig. 7c illustrates this procedure for a fracture plane whose β - and α -angles are 70 and 40 degrees, respectively. First, the β angle is measured clockwise along the β -plane, as shown. Next, a plane containing this point and the downhole axis is constructed. The true dip vector for this fracture is then plotted by measuring the α angle along this great circle, starting from the downhole vector as shown. The downward normal is $90-\alpha$ degrees in the opposite direction along the same great circle.

The above procedure for plotting joint poles is impractical for more than a few planes, however. For the present work, which involved many hundreds of joints, the task was done numerically by transformation of axes. First, a local (core) coordinate system is established based on the hole direction and the β -plane orientation. As shown in Fig. 8, a right-hand system is used, with the local X' axis directed through the $\beta = 0$ degrees position (core reference line). The Y' axis is also in the β -plane, and the Z' axis points uphole. The unit vector normal to a given plane is defined by its direction cosines (x'_n, y'_n, z'_n) in this local system by simple expressions involving the α - and β -angles:

$$\begin{aligned} x'_n &= \cos(\beta + \pi) \cdot \cos \alpha \\ y'_n &= \sin(\beta + \pi) \cdot \cos \alpha \\ z'_n &= -\sin \alpha \end{aligned} \quad (1)$$

These coordinates are then converted into the global (true north) system by the transformation

$$\begin{bmatrix} x_n \\ y_n \\ z_n \end{bmatrix} = \begin{bmatrix} l_1 & l_2 & l_3 \\ m_1 & m_2 & m_3 \\ n_1 & n_2 & n_3 \end{bmatrix} \cdot \begin{bmatrix} x'_n \\ y'_n \\ z'_n \end{bmatrix} \quad (2)$$

The l_i , m_i , n_i terms are direction cosines between the local and global axes, which are computed from the Eulerian angles [16] A, B, and C shown in Fig. 8.

The dip and dip azimuth angles then are found easily from the global direction cosines of the joint unit normal. The BASIC computer code listed and described in the Appendix will perform the complete transformation for an arbitrarily oriented borehole and reference line, once the three angles shown in Fig. 8 have been determined.

Fig. 8. Orientation of local coordinate system for UG-2 relative to true north.

3. RESULTS AND DISCUSSION

3.1 Major Geologic Features

Several structures were identified in the UG-2 core which may be significant in terms of the rock mass behavior or geologic interpretation. The first of these is a prominent fault zone located at a depth of 103 m (339 ft). The gouge material is about 20 cm thick and is a weakly cemented mixture of clay and fractured granitic wall rock, with calcite coatings on some surfaces. The orientation of the fault is estimated to be about $N45^{\circ}E/55^{\circ}SE \pm 5$. A similar zone of fault gouge is located at a depth of 102 m (335 ft); however, it is thinner than the main fault. Sericite is found in some other joints immediately next to the gouge. A greenish-colored zone of hydrothermal alteration consisting mainly of epidote, chlorite and sericite [11] extends about 2m (6.5 ft) into the granitic rock on both sides of the main fault; however, it is not certain that this alteration is associated with the fault alone.

The $N45^{\circ}E/55^{\circ}SE$ orientations observed in the core is similar to that of the fault zone mapped in the canister receiving room [12]. As shown in Fig. 9, the planar projection of the mapped fault is within about 20 m (65 ft) of the above borehole depth. Considering that its orientation may vary somewhat, it is probable that the fault observed in the core is the mapped structure. In addition to this fault zone, several other features were noted. At a depth of 61 m (200 ft), the granitic rock shows a distinctly aplitic texture. This zone was about 1.5 m (4.9 ft) wide, however its orientation could not be determined. Only a few quartz veins were observed; the most prominent is at 145.5 m (477 ft). Its thickness is about 3 cm (1.2 in) and the orientation is estimated to be $N40^{\circ}E/45^{\circ}NW$. Of the many low-angle joints used to orient the core, some were more prominent because of extensive wall rock alteration. Table 1 lists those with alteration widths in excess of 5 cm (2 in). This tabulation serves to indicate the frequency with which prominent features of this type can occur.

Fig. 9. Vertical section through UG-2 showing intersection of receiving room fault.

Table 1. Low-angle joints with greater than 50 mm wall rock alteration.

Depth (ft)	Depth (m)	Dip (deg)	Dip Azimuth (deg)	Gouge Thickness (mm)	Alteration Thickness (mm)
99.91	30.45	22	336	1	130
161.59	49.26	25	42	10	60
184.50	56.24	25	45	1	60
230.52	70.26	26	51	5	600
234.87	71.59	20	22	20	80
241.43	73.59	24	47	1	70
305.42	93.09	28	31	1	90
335.50	102.26	29	29	20	200
341.85	104.20	28	33	5	60
395.77	120.63	17	17	5	120
410.90	125.24	32	32	10	65
434.52	132.44	34	35	13	180

3.2 Statistics of Joint Orientations

Excluding all mechanical breaks caused by drilling or core handling, 1794 natural fractures were logged in UG-2. Figure 10 is an equal-area contour diagram of the poles to all of these. The low-angle set with the assumed $N44^{\circ}W/20^{\circ}NE$ orientation clearly dominates the plot because other joints comprise a small percentage of the total sample. This can be caused by a geometrical sampling bias against observing other joints that are oriented nearly parallel to the borehole axis. Therefore, to display the under-represented data it is helpful to separate the data according to different fracture characteristics. One distinction that can be made is whether features were healed (closed) or broken apart (open) in the core. Figure 11 plots the *pole contours of all healed joints, which accounts for 72 percent of the population in UG-2*. The low-angle set remains dominant in this case. However, if only the open pole contours are plotted (Fig. 12), then many of the low-angle joints are excluded. Several different sets are thus revealed, which are labeled one to four in Fig. 12. The low-angle joints are Set 1. Set 2 strikes $N40^{\circ}W$ and is nearly vertical. The third set strikes $N45^{\circ}E$ and dips $55^{\circ}SE$. Set 4 lies very near the third set with strike $N25^{\circ}E$ and dip $70^{\circ}SE$.

Fig. 10. Contour plot of poles to all natural joints in UG-2.

Fig. 11. Contour plot of poles to all healed (closed) joints.

Fig. 12. Contour plot of poles to all open joints.

Table 2 compares the four joint sets from this study with six sets identified in the SFT-C mapping [4]. Since the SFT-C Set 2 was used as the reference orientation, it corresponds exactly to Set 1 of the UG-2 data. SFT-C Sets 3 and 4 are within 20° of the UG-2 Set 2, which lies about midway between them. UG-2 Sets 3 and 4, whose normals are themselves about 25° apart, each lie within 25° of Set 6 of SFT-C data. There appears to be no correlation between SFT-C Sets 1 and 5 and the UG-2 sets. The lack of precise coincidence between some of the joint sets is not disturbing. This may be due to at least two factors: (1) The UG-2 data is uncorrected for geometrical biasing, unlike the SFT-C mapping data; and (2) the error involved in orienting the UG-2 core may be significant, as discussed earlier.

Table 2. Comparison of joint sets from SFT-C mapping and UG-2 core logging of open joints. Tabulated numbers represent the angles between modal poles to corresponding sets, measured along great circles containing the poles.

	Sets from UG-2 Core Logging			
	(1) N44°W/20°NE	(2) N40°W/VERT	(3) N45°E/55°SE	(4) N25°E/70°SE
Sets from SFT-C Mapping				
(1) N59°E/39°NW	-	-	-	-
(2) N44°W/20°NE	0°	-	-	-
(3) N24°W/VERT	-	10°	-	-
(4) N59°W/VERT	-	19°	-	-
(5) N82°W/VERT	-	-	-	-
(6) N48°E/80°SE	-	-	25°	25°

To compare the UG-2 data with other surveys in the Climax Stock, Fig. 13 summarizes all of the previously reported joint sets and faults [1]. The orientations of UG-2 Sets 2, 3, and 4 in Fig. 12 correspond to faults, rather than joints identified in the previous studies. This distinction may result simply from a difference in terminology used by previous investigators, or the inherent difficulty in discriminating a fault from a joint in a small core sample. Based on the general agreement with the previous set orientations which are themselves somewhat uncertain, a significant change in joint orientations below the SFT-C area is not discernible from the UG-2 data.

Fig. 13. Poles to previously reported discontinuities in the Climax Stock (modified after ref. 1).

Further insight into the characteristics of the UG-2 joint sets can be gained by sorting according to the type of mineralization within the joints. The orientation of all fractures, both open and closed, containing calcite is shown in Fig. 14. This contour diagram corresponds closely with the plot of all open fractures in Fig. 12, which indicates that calcite is common to all four open joint sets. All fractures with pyrite and quartz are represented by Figs. 15 and 16, respectively. In contrast to calcite, these two fillings appear to be confined to just the low-angle joint sets. Other types of mineralization observed in the UG-2 core included clay, iron oxide staining, cericite, aplite, and molybdenite. These observations were few in number, and are shown by the equal-area pole plot in Fig. 17. Most of these fillings are found throughout the four principal joint sets. Sericite and molybdenite are notable exceptions, however, since these occur almost exclusively in the low-angle set. Iron oxide staining is more common to the high-angle joints, however, a few cases also appear in the low-angle set.

Fig. 14. Contour plot of poles to joints containing calcite.

Fig. 15. Contour plot of poles to joints containing pyrite.

EQUAL-AREA STEREO NET PLOT
LOWER HEMISPHERE
248 DATA POINTS

UG-2 QUARTZ

Fig. 16. Contour plot of poles to joints containing quartz.

Fig. 17. Poles to joints containing various minerals.

3.3 Spatial Variations in Joint Orientations

In order to study variation in joint set distribution with depth, Figs. 18a through 18f show pole contours for open fractures within 30 m (100 ft) intervals. (A composite of these six plots would be identical to Fig. 11, the plot for all open fractures.) The presence of the low-angle joints (Set 1) can be seen in all of the interval plots, which is indicative of its ubiquity in the rock mass and the directional bias of the borehole. The orientations of the other three sets, when clearly represented, remain basically the same over the length of the borehole.

Set 3, which strikes about $N45^{\circ}E$ and dips to the southeast, is generally present in all intervals. It is best defined in the two middle intervals (60-120 m), where the number of open fractures is several times higher than in other intervals. The weaker cluster near this set, identified as Set 4, also is seen in all intervals, but usually with lower percentage contours than Set 3. The main conclusion to be drawn is that the NE-striking, high-angle joints (Sets 3 and 4) and the low-angle joints are pervasive.

However, the same does not appear to be true for Set 2 ($N40^{\circ}W/vert.$). Significant concentrations are found only in two intervals, 30-60 m and 90-120 m. The set is not represented at greater than two percent in the 60-90 m interval, which contains the largest population of open joints. Therefore, it appears that this set is not ubiquitous, but rather confined to limited regions of the rock mass.

Fig. 18. Contour plots of poles to open joints in 30 m intervals.

3.4 Joint Frequency and Spacing

Figure 19 shows the frequency of all natural fractures, regardless of set designation, over 7.6 m (25 ft) intervals of UG-2, with cross-hatched areas representing open joints. For most of the hole, the frequency is 7 to 10 fractures per meter (2 to 3 per ft). Two zones are particularly high, however: 61-76 m (200 to 250 ft) and 99-107 m (325 to 350 ft). The latter corresponds to the fault zone described previously at 103 m (339 ft). Most of the fractures in this interval are open, and their orientations are shown in Fig. 20. The principal cluster is distributed around the fault and near Set 3. In this case, the anomalously high frequency of open fractures is associated with a major geologic discontinuity. It is likely that the surrounding fracture zone follows the fault for substantial distance, thus constituting a zone of weakness several meters wide in the rock mass.

Fig. 19. Fracture frequency in UG-2.

Fig. 20. Contour plot of poles to open joints from 99 to 107 m depth.

Fig. 21. Contour plot of poles to open joints from 61 to 76 m depth.

A similar situation applies to the interval from 61 to 76 m. Figure 21 shows that most of the open fractures in this zone fall in the low-angle category (Set 1). The most conspicuous of these low-angle joints are at depths of 70.3 and 71.6 m (see Table 1). These two features consist of relatively thick clay fillings in the joints, surrounded by hydrothermal alteration zones containing epidote and chlorite. Since no other discontinuities of such prominence were logged, the high fracture frequency probably indicates that the zone of dense fracturing follows these particular low-angle features.

Joint spacing, the inverse of frequency, is typically plotted in the form of a histogram, in order to evaluate whether the joints are regularly spaced or randomly distributed. According to Priest and Hudson [13], randomly positioned joints theoretically should produce a negative exponential distribution, whereas clustered or regularly spaced joints do not. In this context, the term "random" means that the presence of one joint does not affect the location of another. Assuming this to be a Poisson process, then leads to a negative exponential spacing distribution. The negative

exponential is expressed by

$$f(x) = \lambda e^{-\lambda x}, \quad (3)$$

where $f(x)$ is the frequency of a joint spacing x , and λ is the average number of joints per unit length. In this distribution, both the mean and standard deviation are equal to $1/\lambda$.

To evaluate the UG-2 data according to this concept, Figs. 22 through 25 present histograms of the joint spacings for various categories. In each figure, a negative exponential curve is superimposed by multiplying the frequency of a particular spacing value by the total number of observations times the class interval of the histogram. Figure 22 indicates that the total joint population follows the negative exponential distribution quite closely, with a mean spacing of about 0.1 m (1/3 ft). Figure 23 plots just the open joint spacings, for which the theoretical distribution does not fit as closely, particularly in the spacing interval of 0 to 0.12 m (0.4 ft). According to Priest and Hudson [13], this suggests that the open fractures are not random, but tend to occur in clusters of dense fracturing. As previously pointed out, the dense zones of open joints are associated with prominent faults and clay-filled, highly altered low-angle joints.

Fig. 22. Joint spacing histogram for all natural fractures.

Fig. 23. Joint spacing histogram for open joints.

Spacing distributions for Sets 1 and 3, which are the two most populated, are shown in Figs. 24 and 25, respectively. In Fig. 24, Set 1 follows a negative exponential curve quite well and therefore are considered to be randomly positioned. The mean spacing is about 0.3 m (1.0 ft). In Fig. 25, however, Set 3 apparently does not conform as well to the theoretical curve. This may be due to a more regular joint spacing (less random), or it may simply reflect the smaller population of the Set 3 sample.

Fig. 24. Joint spacing histogram for low-angle joints (Set 1).

Fig. 25. Joint spacing histogram for Set 3.

4. CONCLUSIONS

A procedure for logging geologic discontinuities in non-oriented core has been presented. Two different means of compiling core data have been used: The simple tabular format, rather than a sketched core log, has proved to be more efficient for recording joint data. An approximate method of core orientation, based on certain geologic features of presumably known orientation, has been demonstrated. The accuracy of this technique is estimated to be within ten degrees; however, it would be desirable to check this in the event a more reliable orientation for the core were available in the future. Considering the inherent uncertainty of this method, the joint set orientations obtained from this study over a vertical range of 150 m are remarkably similar to previous data.

It is recommended that the data presented here be studied more thoroughly in the context of the overall structural geology of the Climax Stock. The question of whether or not the joint pattern in the quartz monzonite is homogeneous should be re-evaluated as further data is acquired. Our tentative conclusion is that it appears to remain the same down to at least 150 m (500 ft) below the SFT-C. From the standpoint of major discontinuities, two highly sheared or faulted zones in the UG-2 core were identified, one of which can be correlated to a fault zone mapped in the SFT-C Receiving Room.

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APPENDIX

USER'S GUIDE FOR FRACTURE LOG TRANSFORMATION PROGRAM

- (1) Determine orientation of reference line ($\beta = 0^\circ$) by any conventional means of core orientation or by reference to known geologic features. The stereographic projection may be used for locating first the β -plane, then the $\beta = 0$ position. The program uses the following convention for the local (borehole) coordinate system: The x' -axis is in the $\beta = 0^\circ$ position (reference line), the y' -axis is $\beta = 270^\circ$ (90° counter-clockwise from $\beta = 0$, looking downhole), and the z' -axis is along the core axis and opposite to the direction of drilling ("uphole").
- (2) Input the bearing and plunge (dip) of the borehole as requested. The plunge of a hole drilled upward is entered as the negative of its inclination above horizontal.
- (3) Input the location of the core reference line (x' -axis). Looking in the direction of drilling, this is measured as the counter-clockwise angle between the three o'clock (true horizontal) position on the β -plane projection and the $\beta = 0^\circ$ position. This number will be between 0 and 180° for an x' -axis in the upper hemisphere.
- (4) Input α and β angles from core log as required; the true dip and dip azimuth are then printed. This is done by first calculating direction cosines in the local system for the downward normal to a fracture plane, then transforming to the global system, and finally calculating the true dip and dip azimuth.

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100 REM FRACTURE LOG TRANSFORMATION PROGRAM
105 REM GIVES TRUE DIP AND DIP AZIMUTH FOR LOCAL ALPHA & BETA
110 REM CODED BY R. THORPE, SEPTEMBER 1983
120 REM *****
130 SET DEGREES
140 PAGE
150 PRINT "ENTER DIRECTION OF DRILLING, CLOCKWISE FROM NORTH: "
160 INPUT A
170 A=A
180 PRINT "ENTER HOLE INCLINATION: "
190 INPUT B
200 B=90-B
210 PRINT "ENTER ANGLE OF REFERENCE LINE ON CORE: "
220 INPUT C
225 REM (A,B,C ARE EULERIAN ANGLES AS DEFINED IN GOLDSTEIN'S
226 REM "CLASSICAL MECHANICS", P.107)
230 REM COMPUTE DIRECTION COSINES
240 S1=SIN(A)
250 S2=SIN(B)
260 S3=SIN(C)
270 C1=COS(A)
280 C2=COS(B)
290 C3=COS(C)
300 L1=C3*C1-C2*S1*S3
310 L2=-S3*C1-C2*S1*C3
320 L3=S2*S1
330 M1=C3*S1+C2*C1*S3
340 M2=-S3*S1+C2*C1*C3
350 M3=-S2*C1
360 N1=S3*S2
370 N2=C3*S2
380 N3=C2
390 PRINT "TRANSFORMATION MATRIX IS: "
400 PRINT "L1,L2,L3: "L1,L2,L3
410 PRINT "M1,M2,M3: "M1,M2,M3
420 PRINT "N1,N2,N3: "N1,N2,N3
430 PRINT "ENTER ALPHA AND BETA FOR FRACTURE:"
440 INPUT A1,B1
450 REM COMPUTE LOCAL DIRECTION COSINES OF DOWNWARD NORMAL
460 X1=COS(A1)*COS(-B1-180)
470 Y1=COS(A1)*SIN(-B1-180)
480 Z1=-SIN(A1)
485 REM PRINT "X1="X1," Y1="Y1," Z1="Z1
490 REM TRANSFORM TO GLOBAL
500 X=L1*X1+L2*Y1+L3*Z1
510 Y=M1*X1+M2*Y1+M3*Z1
520 Z=N1*X1+N2*Y1+N3*Z1
530 IF Z<0 THEN 570
540 X=-X
550 Y=-Y
560 Z=-Z
570 REM COMPUTE GLOBAL DIP & DIP AZIMUTH
575 REM PRINT "X="X," Y="Y," Z="Z
580 D=ACS(-Z)
590 REM COMPUTE BETA FOR NORMAL (CCW FROM EAST)
600 IF X<0 THEN 650
610 B2=90
620 IF Y<0 THEN 720
630 B2=270
640 GO TO 720
650 B2=ATH(Y/X)
660 IF Y<0 THEN 700
670 IF X>0 THEN 690
680 B2=B2+180
690 GO TO 720
700 B2=B2+180
710 IF X<0 THEN 720
720 REM COMPUTE BETA FOR DIP (CCW FROM EAST)
730 B2=B2+180
740 IF B2<360 THEN 760
750 B2=B2-360
760 REM COMPUTE BETA CLOCKWISE
770 B2=360-B2
780 REM COMPUTE AZIMUTH CLOCKWISE FROM NORTH
790 B2=B2+90
800 IF B2<360 THEN 820
810 B2=B2-360
820 REM PRINT RESULTS
830 PRINT "DIP = "D" DEG"
840 PRINT "DIP AZIMUTH = "B2" DEG"
850 GO TO 430
860 END

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