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TRUE LOCATION AND ORIENTATION OF FRACTURES LOGGED WITH THE ACOUSTIC TELEVIEWER (INCLUDING PROGRAMS TO CORRECT FRACTURE ORIENTATION)

By R. A. Kierstein

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
feet (ft)	0.3048	meters (m)

TRUE LOCATION AND ORIENTATION OF FRACTURES LOGGED WITH THE ACOUSTIC TELEVIEWER (INCLUDING PROGRAMS TO CORRECT FRACTURE ORIENTATION)

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ABSTRACT

The attitude of fractures measured on acoustic-televiewer logs may be misorientated by as much as 180° in a drill hole that is deviated significantly from vertical, because of the effect of the vertical component of the magnetic field on the tilted magnetometer that is used to orient the log. A method has been developed to correct for the misorientation by analyzing the orientation of the magnetometer with respect to the magnetic-field vector at the magnetometer's center. Computer programs were written to correct the attitude of fractures for both magnetic effects and hole deviation. For the reorientation of a single fracture, a stereographic solution is illustrated. Test results indicate that the fracture orientation can be corrected to plus or minus 5° of true orientation, provided there are no other magnetic effects, such as magnetite in the rocks.

INTRODUCTION

The location, orientation, and characterization of fractures are important in reservoir engineering, waste disposal, and other geosciences. The acoustic televiewer is a geophysical well-logging device used to provide the location and orientation of fractures and other planar features that intersect a drill hole. Televiewer logs can be misoriented if the hole logged is deviated from vertical. This misorientation error has geometric and magnetic components. This report shows how these logs can be corrected with the aid of a hole survey.

The acoustic televiewer (Zemanek, 1969) produces an image of the borehole wall in two dimensions. Planar fractures that are perpendicular or parallel to the borehole appear as straight lines; other angles of intersection produce sinusoids (fig. 1). The triggering of the televiewer is sensitive to the component of the Earth's magnetic field that is perpendicular to the axis of the tool. When the instrument is tilted, changes in the vertical component of the magnetic field affect the direction in which the magnetometer detects magnetic north. For this reason, holes that are deviated to the north may produce televiewer logs with as much as an 180° error in fracture orientation; holes deviated to the south may cause little or no magnetic error. To correct for the magnetic effect, the location and orientation of the borehole needs to be described mathematically; this is the subject of the next section.

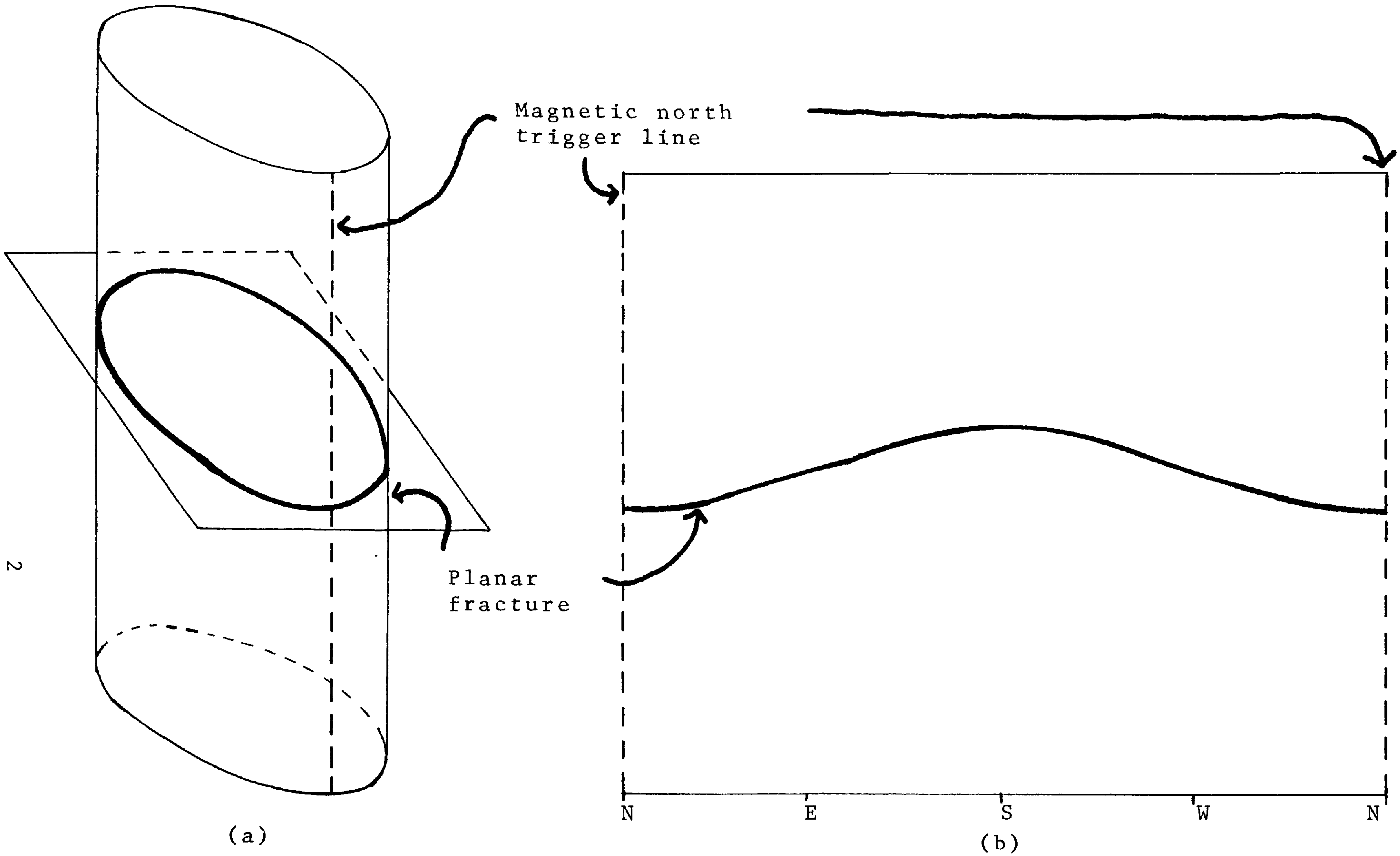


Figure 1.--Three-dimensional sketch of borehole with intersecting planar fracture (a), and the corresponding two-dimensional televiewer log (b).

HOLE-SURVEY METHODS

Several different methods are used to mathematically describe the path of a deviated borehole (Craig and Randall, 1976). However, the programs in this report were written to use only one of the following methods: minimum-curvature, radius-of-curvature, or tangential. Variables used in the programs and the corresponding equations are illustrated in figure 2. For further information on the derivation of the following formulas, consult Wilson (1968) and Turner (1980).

Minimum-Curvature Method

The minimum-curvature method fits a circular arc between two stations, by using a dogleg angle (an angle representing the curvature of the borehole's path between two survey stations) and a ratio factor. The following equations define the dogleg angle (D), the ratio factor (RF), the difference in latitude between survey stations (ΔN), the difference in depth between survey stations (ΔV), and the difference in departure between survey stations (ΔE):

$$D = \arccos\{\cos(I2-I1)-[\sin(I1)\sin(I2)][1-\cos(A2-A1)]\}, \qquad (1)$$

$$RF = [2/D]\ [\tan(D/2)], \qquad (2)$$

$$\Delta N = [\Delta MD/2]\ \{[\sin(I1)\cos(A1)] + [\sin(I2)\cos(A2)]\}\ RF, \qquad (3)$$

$$\Delta V = [\Delta MD/2]\ [\cos(I1) + \cos(I2)]\ RF, \text{ and} \qquad (4)$$

$$\Delta E = [\Delta MD/2]\ \{[\sin(I1)\sin(A1)] + [\sin(I2)\sin(A2)]\}\ RF. \qquad (5)$$

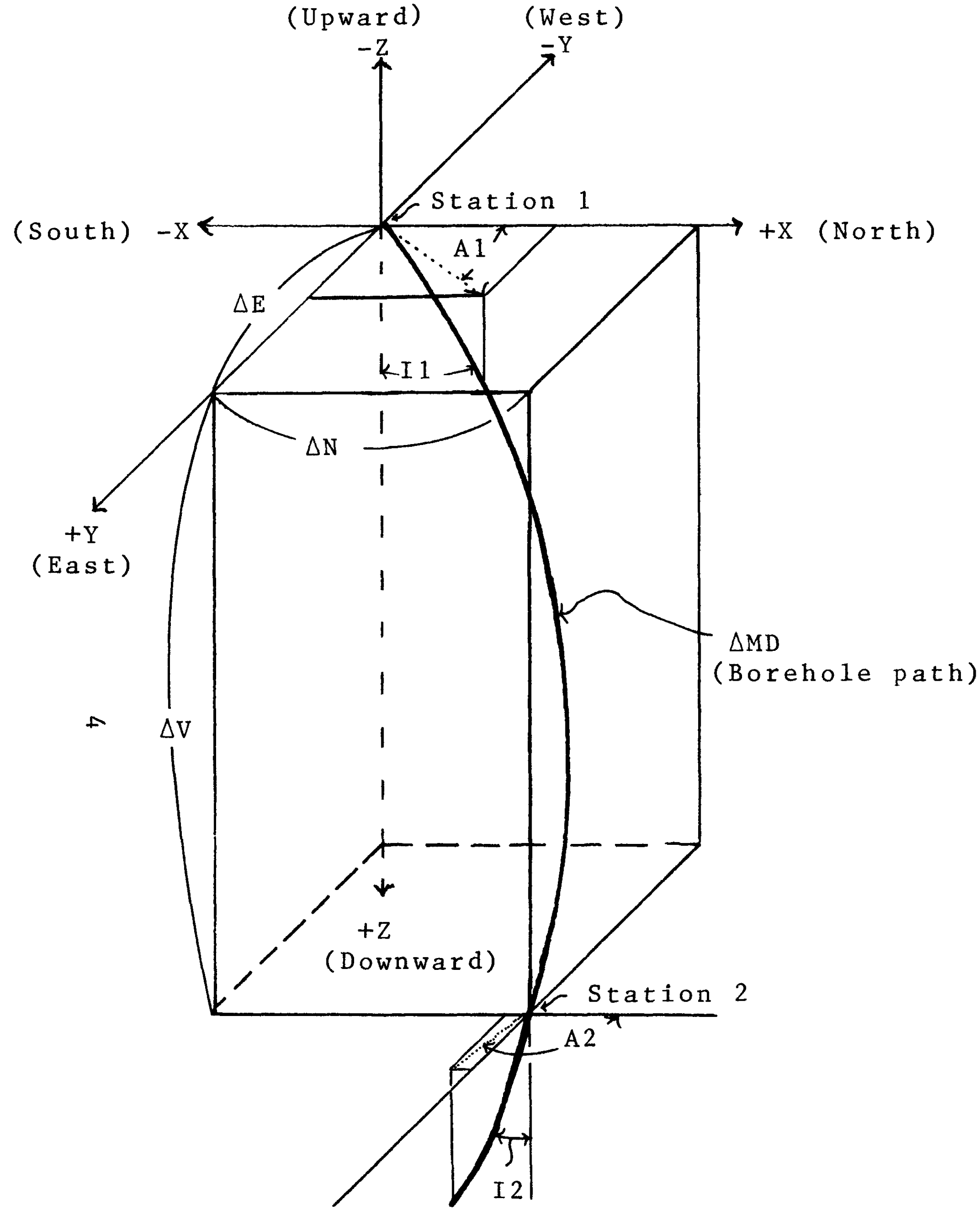
The programs assume that the borehole is straight throughout the length that the fracture intersects the hole. The new azimuth, A(new), and new inclination, I(new), of this straight segment are calculated by interpolation between two bounding stations, 1 and 2:

$$I(new) = I1 + \{[MD(new) - MD(1)][(I2-I1)/\Delta MD]\}, \text{ and} \qquad (6)$$

$$A(new) = A1 + \{[MD(new) - MD(1)][(A2-A1)/\Delta MD]\}, \qquad (7)$$

where MD = measured depth.

A1, A2, I1, I2, and MD are defined in figure 2. New angles, I(new) and A(new), are used to calculate the location of the fracture center, (depth to bottom of sinusoid - depth to top of sinusoid)/2 + depth to top of sinusoid, as well as to find the true orientation of the fracture plane as explained in the following section on geometrical rotation. Specifically I(new) and A(new) are used as I2 and A2 in equations (1) through (5) to calculate the differences in latitude, departure, and depth between the fracture center and the station above it (station 1). The differences are then added to the values at station 1 to obtain the latitude, departure, and depth to the fracture center.



EXPLANATION

ΔMD	MEASURED DISTANCE BETWEEN SURVEY STATION 1 AND STATION 2.
A1	AZIMUTH AT STATION 1 MEASURED FROM MAGNETIC NORTH.
I1	MEASURED INCLINATION ANGLE AT STATION 1 (FROM VERTICAL OR +Z AXIS).
A2	AZIMUTH AT STATION 2.
I2	INCLINATION AT STATION 2.
ΔN	DIFFERENCE IN LATITUDE: = LATITUDE (2) MINUS LATITUDE (1).
ΔV	DIFFERENCE IN DEPTH: = DEPTH (2) MINUS DEPTH (1).
ΔE	DIFFERENCE IN DEPARTURE BETWEEN THE UPPER AND LOWER STATION: = DEPARTURE (2) MINUS DEPARTURE (1).

Figure 2.--Directional-survey parameters.

Radius-of-Curvature Method

The radius-of-curvature method also fits a circular arc between two bounding-survey stations. The following equations define ΔN, ΔV, and ΔE between the stations:

$$\Delta N = MD[\cos(I1)-\cos(I2)]\,[\cos(A1)-\cos(A2)]/[(I2-I1)(A2-A1)], \quad (8)$$

$$\Delta V = MD[\sin(I2)-\sin(I1)]/(I2-I1), \text{ and} \quad (9)$$

$$\Delta E = MD[\cos(I1)-\cos(I2)]\,[\sin(A2)-\sin(A1)]/[(I2-I1)(A2-A1)]. \quad (10)$$

Note that the quantities (I2-I1) and (A2-A1) of the above equations need to be in radians, which are dimensionless. The new angles, I(new) and A(new), and new coordinates at the fracture center are calculated in the same manner as shown in the minimum-curvature method.

This method is sensitive to small changes in angles. If the change in inclination or azimuth is too small, a division by zero will occur in equations (8) through (10), which will lead to significant errors in both the location and attitude of the fracture. In such cases, the minimum-curvature method needs to be used.

Tangential Method

The tangential method assumes the borehole to be a straight, inclined line, with an azimuth (A) and an inclination (I). ΔN, ΔV, ΔE are then expressed as:

$$\Delta N = \Delta MD[\sin(I)\cos(A)], \quad (11)$$

$$\Delta V = \Delta MD[\cos(I)], \text{ and} \quad (12)$$

$$\Delta E = \Delta MD[(\sin(I)\sin(A)]. \quad (13)$$

The tangential method is provided with these programs to give the user flexibility. It should be reiterated that borehole surveys are reported from true north, and televiewer logs are referenced to magnetic north. Therefore, the programs subtract the declination angle from station azimuths, and further calculations are made with angles that are referenced to magnetic north, but the final results are reported with respect to true north.

GEOMETRICAL ROTATION

After determining the azimuth and inclination of the borehole with respect to magnetic north, the strike and dip of the fracture needs to be described in terms of a surface-coordinate system (X, Y, and Z in fig. 3). The relationship between the acoustic-televiewer log, the borehole-coordinate system (x, y, and z in fig. 3), and the parameters needed to calculate the attitude of the fracture in the surface-coordinate system are illustrated in figure 3. The five angles needed to perform this conversion are:

A = hole azimuth (between 0° and 360°),

D = hole dip (between 0° and 90°),

P = apparent dip of fracture,

Dp = apparent down-dip azimuth of the fracture, and

K = apparent strike of fracture (K = Dp - 90°).

The adjective "apparent" is used to describe angles that are referenced to the skew borehole-coordinate system. Conventionally, strike is referenced to the northern quadrants; however, for this paper, the strike is the azimuth (between 0° and 360°) of the feature, so that the down-dip direction of the feature is always given by the strike-azimuth angle + 90°. In other words, the down-dip direction of a fracture is always in a clockwise direction from the given strike azimuth, never in a counter-clockwise direction.

Using the televiewer log illustrated in figure 3(c), the important parameters Dp, K, and P are calculated in the following manner. First the lowest point of the sinusoid is located [shown in fig. 3(b) and 3(c) as a ★], and the azimuth of this point is read from the log. This azimuth is (Dp), the apparent down-dip azimuth; in this case it equals 135°. Next, the apparent strike of the fracture (K) is determined by subtracting 90° from (Dp), apparent down-dip azimuth of the fracture; in this case it equals 45°. Finally, the apparent dip angle (P) is calculated by taking the inverse tangent of (h), (the total height of the sinusoid), divided by the hole diameter. It is important to note that both the height (h) and the hole diameter needs to be in the same units. The apparent dip angle (P), therefore, equals the arctan(3/0.25) or 85°. To summarize:

Dp = apparent down-dip azimuth = 135°,

K = Dp - 90° = 45°, and

P = arctan(h/hole diameter) = arctan(3/0.25) = 85°.

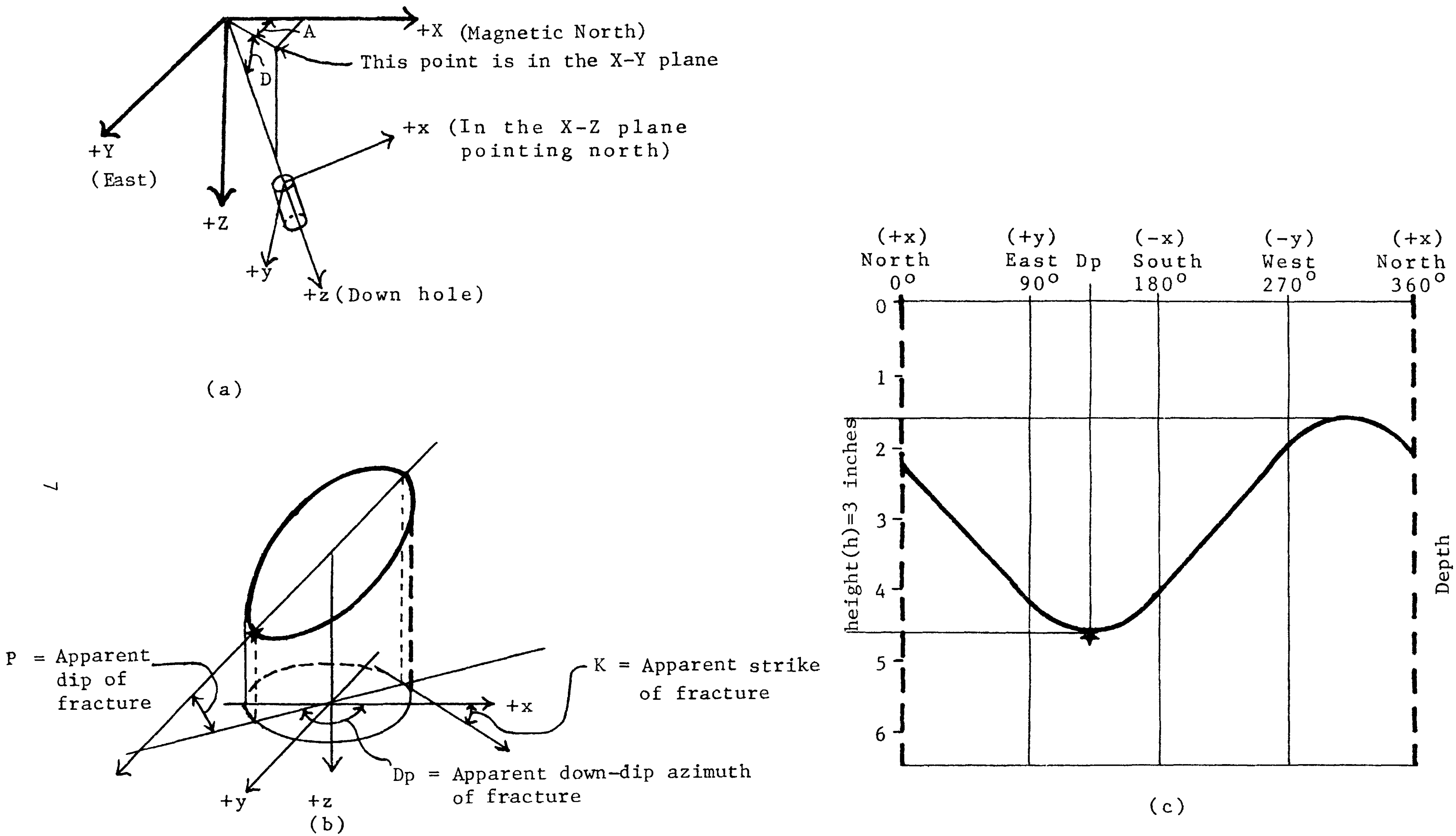


Figure 3.--Coordinate-system relationships: surface-coordinate-system (in capitals); borehole-coordinate system (in small letters) (a); an intersecting fracture (b) with the corresponding log (c).

For calcuation purposes, the fracture plane is described in terms of its unit normal. This unit normal is expressed as three directional cosines αf, βf, and γf (fig. 4). These directional cosines are defined by the following equations:

$$B = \sqrt{\tan^2(D) + \cos^2(A)}, \tag{14}$$

$$\alpha f = -[\cos(P)\cos(A)\cos(D)] - [\sin(P)/B]\{[\sin(K)\tan(D)] + [\cos(K)\sin(A)\cos(A)\cos(D)]\}, \tag{15}$$

$$\beta f = [B\sin(P)\cos(K)\cos(D)] - [\cos(P)\sin(A)\cos(D)], \text{ and} \tag{16}$$

$$\gamma f = [\sin(P)/B]\{[\sin(K)\cos(A)] - [\cos(K)\sin(A)\sin(D)]\} - [\cos(P)\sin(D)]. \tag{17}$$

Once the directional cosines are known, the surface-coordinate fracture dip, surface-coordinate down-dip azimuth, and the surface-coordinate fracture strike are defined by the following relations:

Surface-coordinate fracture dip = arccos (γf)

Surface-coordinate down-dip azimuth = arctan ($\beta f/\alpha f$), and

Surface-coordinate fracture strike = arctan ($\beta f/\alpha f$) - 90°.

As shown in figure 4, these relationships are only valid if the unit normal is in the upper hemisphere, which corresponds to a negative γf. If a positive γf is obtained when rotating a fracture, the programs choose the other normal by reversing the signs of αf, βf, and γf. The program also checks for limiting cases, such as a vertical fracture, when $\gamma f = 0$, or when $\beta f/\alpha f$ approaches infinity (an east-west dip line). In these cases, the program makes the appropriate substitutions.

To this point, all the calculations made have assumed that the televiewer triggers in the north-south plane. This is not necessarily an accurate description of the triggering mechanism, as shown in the next section called magnetic effect. However, when the hole is nearly vertical, the tool is triggering correctly, and there is no need to make a magnetic correction. Therefore, the programs include an option to make no magnetic-effect correction. In such a case, the programs would report the true strike as the surface-coordinate fracture strike plus the declination angle; in a similar manner, true down-dip azimuth would be reported as the surface-coordinate down-dip azimuth plus the declination angle. This addition of the declination angle references the angles to true north rather than to magnetic north.

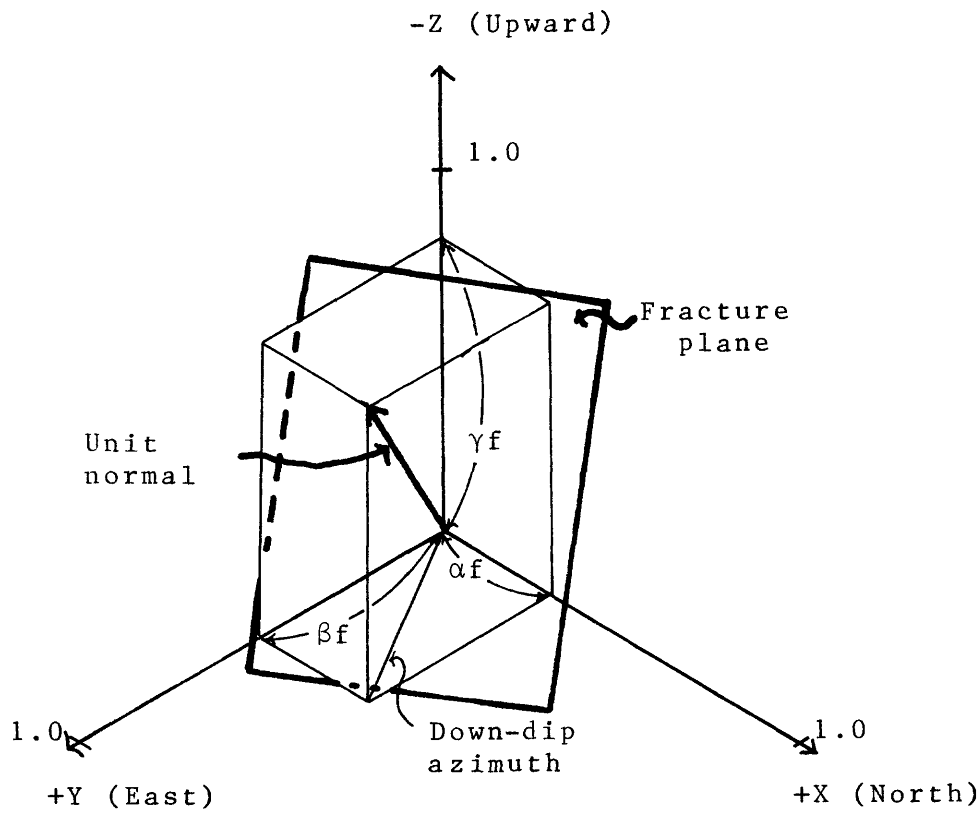


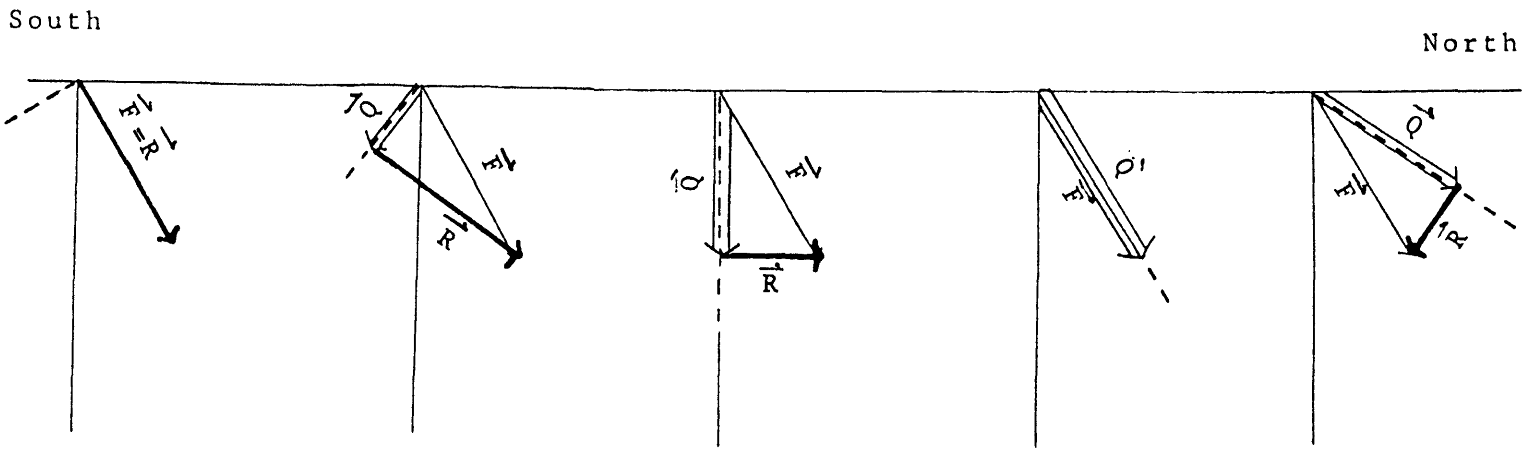
Figure 4.--Three-dimensional sketch of a fracture plane, the unit normal, and the directional cosines defining that normal.

MAGNETIC EFFECT

The effects of the vertical component of the magnetic field on the orientation magnetometer, and the corrections for these effects in the programs are explained in this section. The orientating magnetometer in the acoustic televiewer is sensitive to the component of the earth's magnetic field that is perpendicular to the axis of the tool. When the instrument is tilted, the vertical component of the magnetic field also affects the direction in which the televiewer detects north; hence, that component changes the position at which each sweep on the televiewer log is started. The effect of the magnetometer for different borehole orientations is illustrated in figure 5. The components shown in this figure are all in the north-south plane. Vector F is at the center of the magnetometer.

An 180° reversal in triggering direction is illustrated in figure 5. In figure 5(a), the borehole is perpendicular to the magnetic-field vector. The triggering component of each sweep, R (the component of the magnetic-field vector perpendicular to the borehole), has the same magnitude and direction as the magnetic-field vector; therefore, no misorientation of the log occurs. No misorientation occurs when the borehole is inclined to the south, as shown in figure 5(b). When the borehole is inclined in such a manner, the magnetic-field vector can be represented by two components: a vector Q that is parallel to the borehole axis and a vector R that is perpendicular to the borehole axis. Note that if figure 5 were not in the north-south plane, the small change in direction of the vector R from figure 5(a) to figure 5(b) would cause a small change in the triggering of each sweep. When the borehole is vertical, the magnetometer is triggering each sweep correctly at the northern-most position as shown in figure 5(c). Note that as the orientation of the borehole approaches the direction of the magnetic-field vector, the magnitude of the triggering component is decreased. The borehole and magnetic-field vectors coincide in figure 5(d); therefore, the triggering component is zero. In this case, the magnetometer cannot correctly trigger, and the logs are misorientated. As the hole dip becomes smaller, the direction of the triggering component changes from north to south. It is this change in the triggering component that produces an incorrectly orientated log. This 180° change is shown in figure 5(e). In this case, a fracture actually dipping to the north would be shown as dipping to the south on the televiewer log.

Steel casing or a concentration of a magnetic mineral such as magnetite also can cause orientation errors. Two logs of the same hole are shown in figure 6. The sweeps were triggered by the magnetometer in figure 6(b), but they were not in figure 6(a). Note the wandering lines in figure 6(b); these lines indicate changes in the orientation of the trigger pulse from the magnetic effects of casing.



(a) Borehole perpendicular to the magnetic-field vector.

(b) Borehole inclined to the south.

(c) Borehole vertical.

(d) Borehole and magnetic-field vector parallel.

(e) Borehole inclined to the north more than the magnetic-field vector.

EXPLANATION

$\vec{F}$ ⟶ MAGNETIC-FIELD VECTOR AT MAGNETOMETER'S CENTER.

$\vec{Q}$ ⟹ COMPONENT OF THE MAGNETIC-FIELD VECTOR PARALLEL TO THE BOREHOLE.

$\vec{R}$ ⟶ COMPONENT OF THE MAGNETIC-FIELD VECTOR PERPENDICULAR TO THE BOREHOLE (TRIGGERING COMPONENT).

------- BOREHOLE AXIS.

Figure 5.--Different borehole orientations in the north-south plane, illustrating a 180° reversal in the triggering component; reversal has occurred in (e).

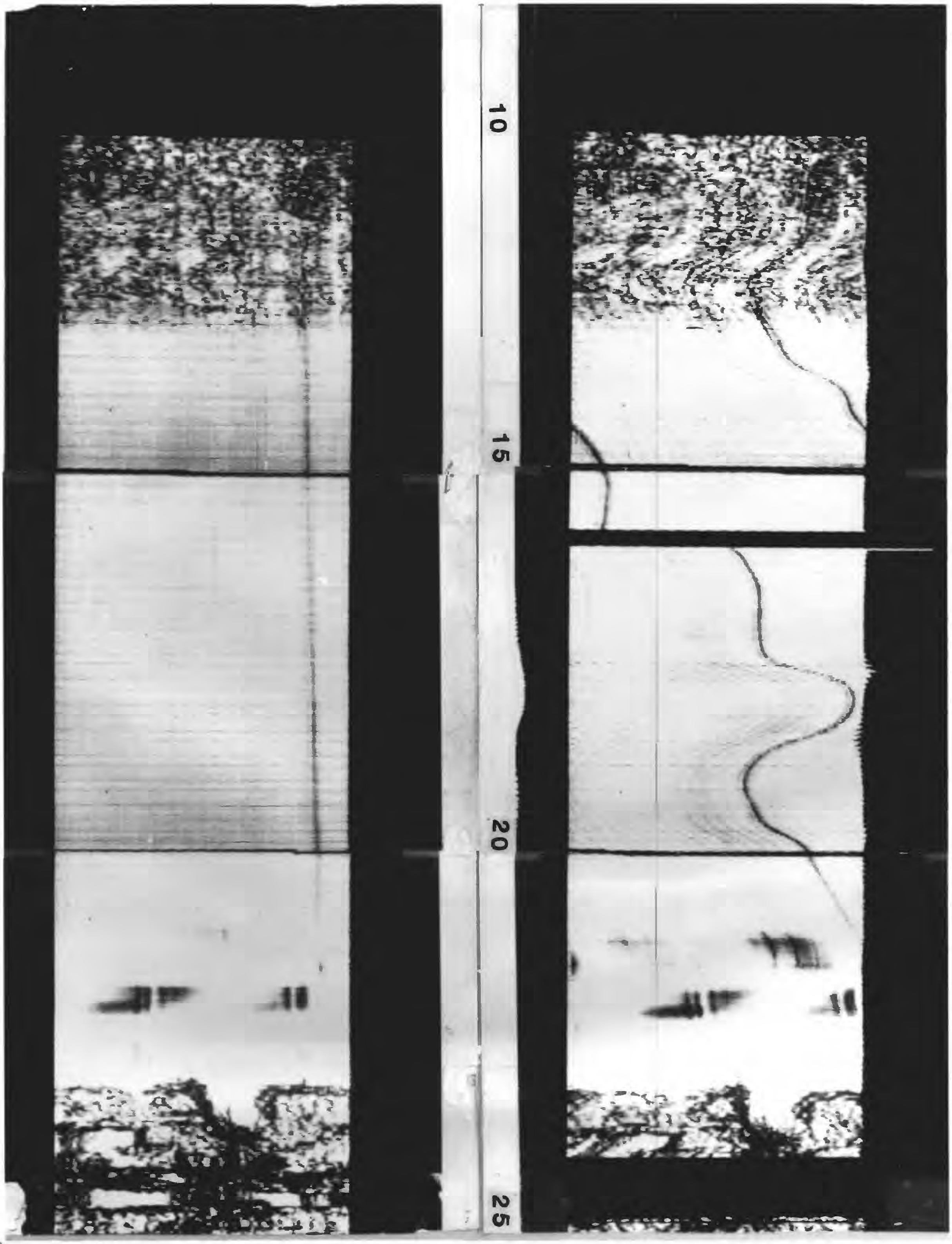


Figure 6.--Televiewer log of casing with switch triggering (a); the same casing shown with magnetic triggering (b).

A map view of the triggering component (R) and a due north component (N) is shown in figure 7. The vector N is defined by the intersection of a north-south plane, and a plane perpendicular to the hole axis at the center of the fracture. Holes deviated to the south are less susceptible to orientation errors, as indicated in figure 7.

To correct for these errors, consider the vectors involved:

1. The vectors in figure 5(c) are

   a. Magnetic field vector (given an arbitrary magnitude of 1) is

   $$\vec{F} = \cos(V)\hat{i} + \sin(V)\hat{k}, \qquad (18)$$

   where V = magnetic inclination angle.

   b. Component parallel to hole axis is

   $$\vec{Q} = [(a)\cos(A)\cos(D)\hat{i}] + [(a)\sin(A)\cos(D)\hat{j}] + [(a)\sin(D)\hat{k}], \qquad (19)$$

   where a = an arbitrary amplitude of the vector R,

   A = the azimuth of the hole, and

   D = the hole dip.

   c. Component perpendicular to the hole axis is

   $$\vec{R} = x\hat{i} + y\hat{j} + z\hat{k}. \qquad (20)$$

2. The magnetic-field vector has two components,

   $\vec{F} = \vec{Q} + \vec{R}$, which yields by equating parts, (21)

   $\cos(V) = [(a)\cos(A)\cos(D)] + x,$

   $0 = [(a)\sin(A)\cos(D)] + y,$ and

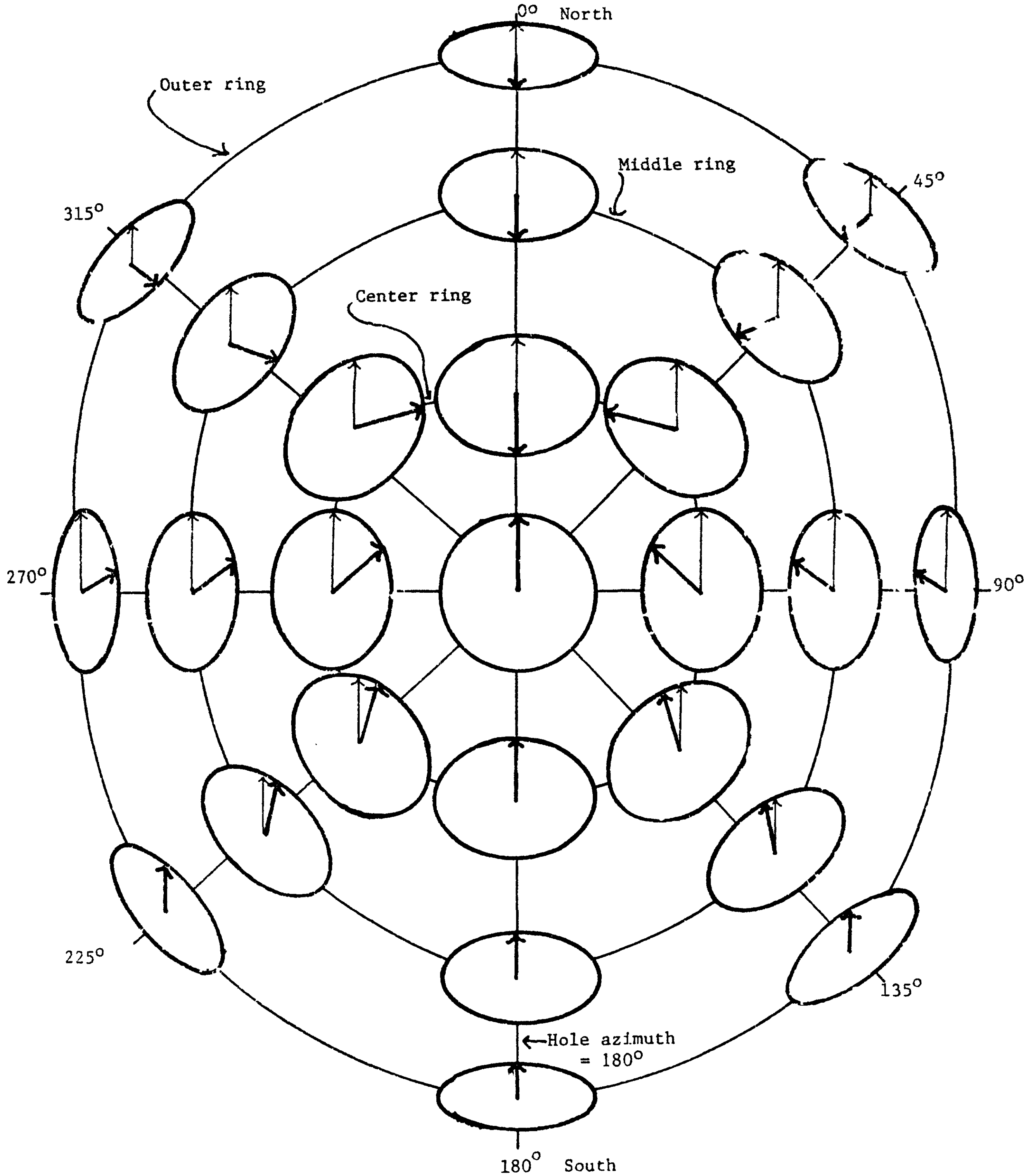
   $\sin(V) = [(a)\sin(D)] + z,$

   which implies that

   $x = \cos(V) - [(a)\cos(A)\cos(D)],$

   $y = -[(a)\sin(A)\cos(D)],$

   $z = \sin(V) - [(a)\sin(D)].$



EXPLANATION

$\vec{N}$ ⟶ PROJECTION OF MAGNETIC FIELD VECTOR.

$\vec{R}$ ⟶ TRIGGERING COMPONENT.

Figure 7.--Map view of inclined holes at different hole azimuths. The center ring of ellipses is inclined at 37°, the middle ring at 53°, and the outer ring at 66°. The azimuth of the hole is indicated by the axis passing through the center of the ellipse. Magnetic inclination of F is 60° (V = 60°).

3. Solving for the amplitude (a),

$$|\vec{F}| = |\vec{Q}| + |\vec{R}| = 1, \qquad (22)$$

$$= [(a)^2\cos^2(A)\cos^2(D)] + [(a)^2\sin^2(A)\cos^2(D)] + [(a)^2\sin^2(D)]$$

$$+ [\cos(V) - (a)\cos(A)\cos(D)]^2 + [(-a)\sin(A)\cos(D)]^2$$

$$+ [\sin(V) - (a)\sin(D)]^2.$$

which when solved for (a) yields

$$(a) = [\cos(V)\cos(A)\cos(D)] + [\sin(V)\sin(D)]. \qquad (23)$$

4. Solving for the magnitude of $\vec{Q}$,

$$\vec{Q} = [\cos(V) - (a)\cos(A)\cos(D)]\hat{i} - [(a)\sin(A)\cos(D)]\hat{j} \qquad (24)$$

$$+ [\sin(V) - (a)\sin(D)]\hat{k}, \text{ or}$$

$$\vec{Q} = \sqrt{1 - (a)^2}. \qquad (25)$$

5. The vector N shown in figure 8 is defined as

$$\vec{N} = [\tan(D)/B]\hat{i} - [\cos(A)/B]\hat{k}, \qquad (26)$$

where $N = 1$, and

$$B = \sqrt{\tan^2(D) + \cos^2(A)}.$$

6. The star (★) in figure 8 indicates the position of an important feature, such as the low point of a sinusoid (fig. 3). When the televiewer is tilted, $\vec{N}$ and $\vec{R}$ are not coincident, as illustrated in figure 8. The tool triggers on $\vec{R}$, not $\vec{N}$. Before the corrections mentioned in the geometrical-rotation section can be made, the angle θ between $\vec{N}$ and $\vec{R}$ needs to be known and appropriately added or subtracted. The angle between $\vec{N}$ and the important feature (★) is $\delta - \theta$, where θ is the angle between $\vec{N}$ and $\vec{R}$ (fig. 8). The angle θ needs to be added to apparent azimuths for hole azimuths between 180° and 360°, and subtracted for hole azimuths between 0° and 180° (fig. 8). The angle θ is obtained by taking the dot product of $\vec{R}$ and $\vec{N}$:

$$\vec{R} \cdot \vec{N} = |\vec{N}|\ |\vec{R}| \cos\theta = RxNx + RyNy + RzNz; \qquad (27)$$

solving for θ yields

$$\theta = \arccos\{[\cos(V) - (a)\cos(A)\cos(D)]\tan(D) \qquad (28)$$

$$- [\sin(V) - (a)\sin(D)]\cos(A)\}/(B|\vec{R}|).$$

EXPLANATION

Dp = APPARENT DOWN-DIP AZIMUTH OF THE FRACTURE.
θ = ANGLE BETWEEN $\vec{N}$ AND $\vec{R}$.
δ = θ + Dp.
$\vec{R}$ ⟶ COMPONENT OF FIELD VECTOR PERPENDICULAR TO THE BOREHOLE.
$\vec{N}$ ⟶ PROJECTION OF MAGNETIC-FIELD VECTOR.

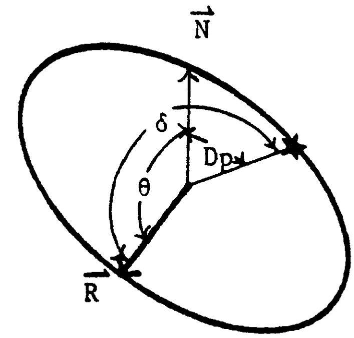


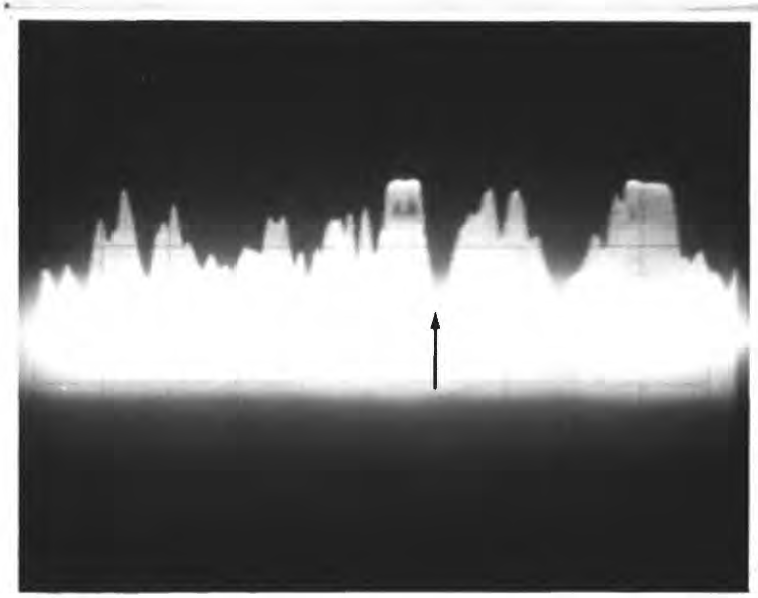
Figure 8.--Angles used in the geometric rotation.

Maps showing the magnetic inclination and declination in the United States can be purchased through the U.S. Geological Survey (1976 for magnetic inclination, and 1980 for magnetic declination). Moffitt and Bouchard (1975, p. 196) give a interpolation technique that can be used between publication of two old maps.

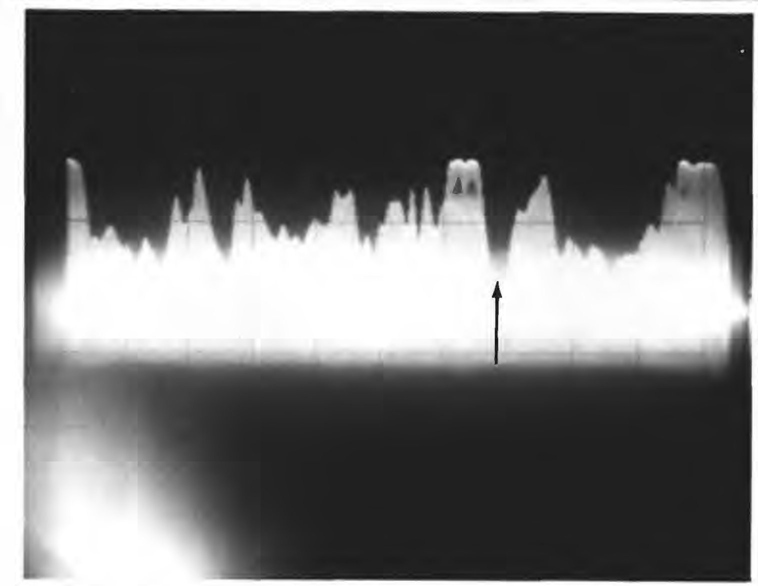
TEST RESULTS

Calculated triggering errors were compared with experimental results. The experiment was conducted in a open field sufficiently removed from power lines and the logging truck to eliminate extraneous magnetic effects. The televiewer was centered in a plastic tube filled with water, and the tube was fastened to a wooden platform that could be tilted to simulate the inclination of a borehole and prevent the tube itself from rotating. The recording instruments were set to examine each 360° sweep of the televiewer signal. A nonmagnetic rod was fixed to the side of the plastic tube. It was the position of this rod that was monitored.

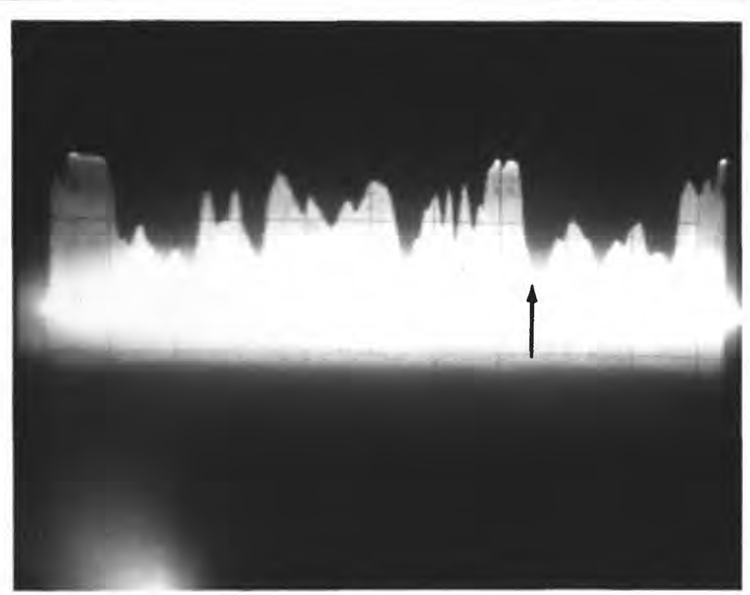
A series of individual sweeps taken at different inclinations for a hole azimuth of 90° are shown in figure 9. The arrows indicate the acoustic response of the televiewer to the rod. Note that as the tool is inclined from vertical the arrows move to the right. The difference between the position of the arrows in figures 9(b) through 9(d) and in figure 9(a) is a measure of the angle θ in equation 28. There were 36 records made with 24 in the northern quadrants. These data indicate that the difference between experimental and calculated orientations is within ±5°, which is an error of 2.8 percent.



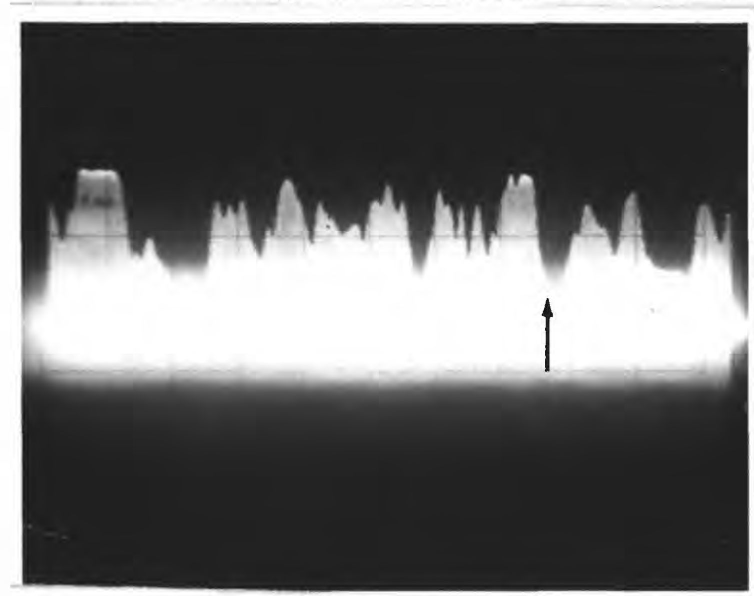
(a) Inclination = 0°.
The rod is at 30 divisions or 216°.



(b) Inclination = 15°.
The rod is at 34 divisions or 245°.
Theoretically, the rod should be at 247°.



(c) Inclination = 43°.
The rod is at 37.5 divisions or 270°.
Theoretically, the rod should be at 274°.



(d) Inclination = 67°.
The rod is at 39 divisions or 281°.
Theoretically, the rod should be at 281°.

Figure 9.--Televiewer sweeps at a hole azimuth of 90°. Each photograph has 50 divisions with grid lines every 5 divisions; each division represents 7.2°.

HAND-HELD-CALCULATOR PROGRAM

The purpose of the calculator program is to allow the user to reorientate a fracture without having to access a large computer. The program is user-oriented; after completing several examples, the user can run the programs without written instructions. The program requires hole-survey data, such as measured depth, angle of inclination, azimuth angle, and the type of calculation technique. All length measurements need to be entered in the same units, and all depths need to be measured from the same reference. All angles need to be entered in degrees, minutes, and seconds. For example, an azimuth of 123°, 36 minutes, and 24 seconds would be entered as 123.3624. The hole azimuth needs to be referenced to true north.

The program was written for a Hewlett-Packard(HP)-41CV[1/] and was designed to run with the peripheral printer. However, with the following modifications, the program can be run without the printer. The program requires almost the entire memory; therefore, all other programs first need to be cleared. Set the size to 41 and clear all key assignments and all flags. If you wish to run the program without the printer, delete the following lines in order: 687, 425, 59, and 17. All of these steps are "ADV", the command for advancing the printer paper. Next, insert a stop after the following "AVIEW" (alpha view) commands: 388, 361, 353, 347, 282, 279, 276, 273, 269, 266, 166, 158, and 149. After running the program several times, the user might desire to change some of the "STOP" commands to "PSE" or pause commands. The "STOP" commands inserted above are now on the following lines: 150, 160, 169, 270, 274, 279, 283, 287, 291, 357, 364, 373, and 401. If only one of the three borehole-survey methods is needed, the following lines may be deleted for any given method: tangent (1-49), minimum-curvature (420-598), or radius-of-curvature (628-832). These are line numbers prior to the changes listed above. If a mistake is made, or it is desired to change to a different survey method, turn the calculator off and then back on; this is done to clear all of the user flags (11-20) and some of the error flags. If the fracture under consideration has an apparent horizontal orientation, then enter zero to the down-dip azimuth prompt when running the program. A listing of register assignments is in table 1 (Supplemental data section); a listing of the program is in table 2 (Supplemental data section). Two examples using this program follow.

Example 1--Simple-Dip Increase

Problem: A hole inclined 30° due west (A = 270°) has a diameter of 0.25 ft. The top of the fracture intersects the borehole at a depth of 100 ft, and the bottom of the fracture intersects at 100.25 ft. The fracture dips due east (Dp = 90°). In this example, all the angles are referenced to true north (fig. 10).

1/ The use of trade names in this report is for identification only and does not constitute endorsement by the U.S. Geological Survey.

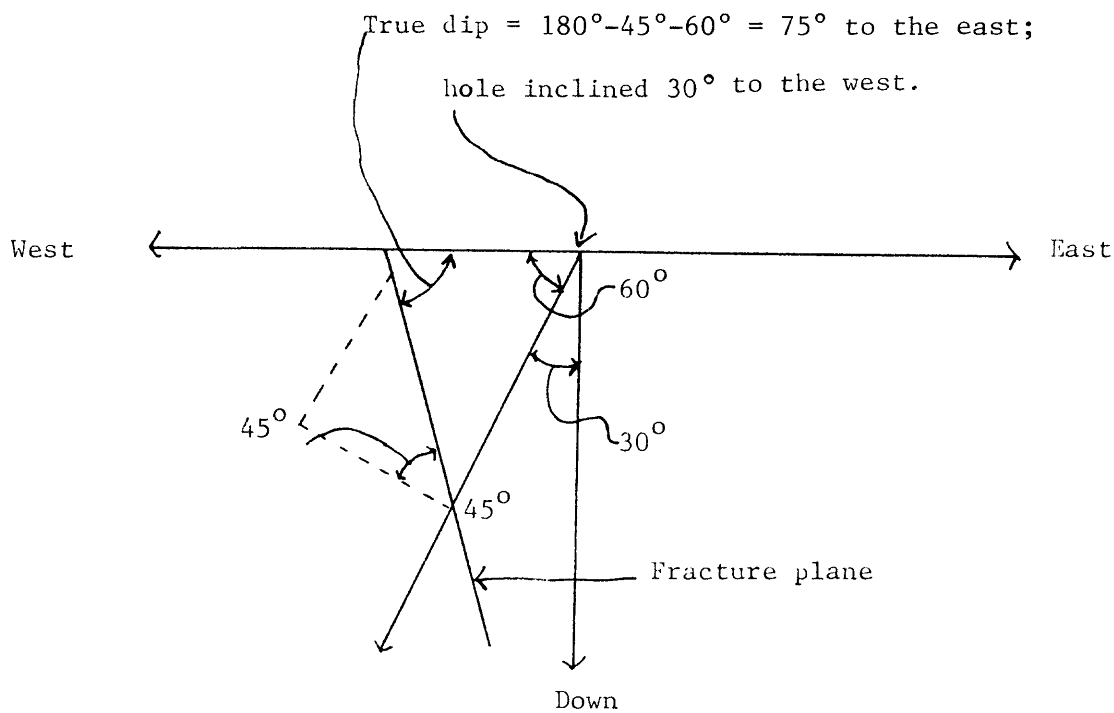


Figure 10. Example problem in east-west plane.

Solution:

Press	Display	Comment
XEQ	XEQ___	
ALPHA	XEQ_	
TANG	XEQ TANG_	
ALPHA	HOLE NAME?	ENTER AS MANY AS SIX ALPHANUMERIC CHARACTERS
HOLE 1	HOLE 1_	
R/S	HOLE NAME = HOLE 1 DECL? +FOR E	ENTER MAGNETIC DECLINATION; POSITIVE FOR DECLINATION EAST OF TRUE NORTH.
0.0	0.0_	
R/S	WITH THETA?	DO YOU WISH TO INCLUDE THE EFFECT OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD? ENTER Y FOR YES OR N FOR NO.

N	N_	
R/S	HOLE DIA?	HOLE DIAMETER?
0.25	0.25_	
R/S	HOLE AZIMUTH?	
270.0	270.0_	
R/S	INC.?	HOLE INCLINATION?
30.0	30.0_	
R/S	FRAC. TOP?	CALCULATOR WILL BEEP AND ASK FOR MEASURED DEPTH TO FRACTURE TOP.
100.0	100.0_	
R/S	FRAC. BOTTOM?	FRACTURE BOTTOM?
100.25	100.25_	
R/S	DOWN DIP AZ?	DOWN DIP AZIMUTH?
90.0	90.0_	
R/S		

ANSWERS:

TOP DEPTH= 100.0000	
BOTTOM DEPTH= 100.2500	
CENTER DEPTH= 100.1250	
TRUE DEPTH= 86.7108	TO FRACTURE CENTER
TRUE DEPARTURE=-50.0625	
TRUE LATITUDE= 0.0000	
DIP= 75.0000	TRUE STRIKE AND DIP.
DIP DIRECTION= 90.0000	DIP DIRECTION INDICATES THE DOWN-DIP AZIMUTH OF THE PLANE.
STRIKE= 0.0000	
FRAC. TOP?	PROMPT FOR NEXT FRACTURE.

ON	TURN CALCULATOR OFF AND ON AGAIN TO CLEAR ALL FLAGS FOR NEXT EXAMPLE.

Example 2--Multiple-Survey Stations

Problem: A hole was surveyed by the minimum-curvature method and the following data were reported:

DEPTH (feet)	AZIMUTH (degrees, minutes)	INCLINATION (degrees, minutes)	TRUE DEPTH (feet)	DEPARTURE (feet)	LATITUDE (feet)
0	N72 08 E	14 30	0.0	0.0	0.0
100	N69 07 E	14 40	96.78	23.74	8.36
200	N70 05 E	15 00	193.45	47.74	17.27
300	N69 21 E	15 20	289.96	72.28	26.34
400	N71 01 E	15 35	386.34	35.38	97.35

Azimuth angles are from true north.
Magnetic declination is 7°, 30 minutes east.
Magnetic inclination is 76°, 50 minutes, and 6 seconds.
Hole diameter is 0.25 ft.

You wish to know the true orientation of three fractures given the following information:

	Fracture 1	Fracture 2	Fracture 3
Fracture top	50 ft	225 ft	376 ft
Fracture bottom	51.08 ft	225.20 ft	406 ft
Down-dip azimuth	90° 29 minutes 56 seconds	45°	231° 30 minutes

Solution:

Press	Display	Comment
XEQ	XEQ_	
ALPHA	XEQ_	
MINC	XEQ MINC_	
ALPHA	HOLE NAME?	
HOLE 2	HOLE 2_	

R/S	DECL? + FOR E	
7.30	7.30_	
R/S	WITH THETA?	
Y	Y_	
R/S	MAG. INC?	MAGNETIC INCLINATION ANGLE?
76.5606	76.5006_	
R/S	HOLE DIA?	
0.25	0.25_	
R/S	STAT. 1 D?	DEPTH TO TOP STATION
0.0	0.0_	
R/S	STAT. 1 A?	AZIMUTH AT STATION 1?
72.08	72.08_	
R/S	STAT. 1 I	INCLINATION AT STATION 1?
14.30	14.30_	
R/S	VERT. DEP 1?	TRUE VERTICAL DEPTH TO STATION 1?
0.0	0.0_	
R/S	DEPART. TO 1?	TRUE DEPARTURE TO STATION 1?
0.0	0.0_	
R/S	LAT. TO 1?	TRUE LATITUDE TO STATION 1?
0.0	0.0_	
R/S	STAT. 2 D?	MEASURED DEPTH TO STATION 2?
100.0	100.0_	
R/S	STAT. 2 A?	AZIMUTH AT STATION 2?
69.07	69.07_	
R/S	STAT. 2 I?	INCLINATION AT STATION 2?
14.40	14.40_	

R/S	FRAC. TOP?	CALCULATOR BEEPS AND PROMPTS FOR FRACTURE TOP?
50.0	50.0_	
R/S	FRAC. BOTTOM?	FRACTURE BOTTOM?
51.08	51.08_	
R/S	DOWN DIP AZ?	DOWN DIP AZIMUTH?
90.2956	90.2956_	
R/S		

ANSWERS:

```
TOP DEPTH= 50.000
BOTTOM DEPTH= 51.0800
CENTER DEPTH=50.5400
TRUE DEPTH= 48.9210
TRUE DEPARTURE=12.0241
TRUE LATITUDE= 4.0538
DIP= 65.1360
DIP DIRECTION 32.3004
STRIKE= 302.0004
```

	SAME STAT.?	SAME STATIONS FOR NEXT FRACTURE ENTER N FOR NO, Y FOR YES
N	N_	
R/S	STA 2 NOW 1?	IS STATION 2 NOW THE TOP STATION. IN OTHER WORDS IF WE HAD A FRACTURE LOCATED AT 103 FT THE ANSWER WOULD BE YES BUT SINCE THE NEXT FRACTURE IS AT 225 FT THE ANSWER IS NO ENTER Y FOR YES OR N FOR NO
N	N_	
R/S	STAT. 1 D?	
200.0	200.0_	
R/S	STAT. 1A?	
70.05	70.05_	
R/S	STAT. 1 I?	

15.00	15.00_
R/S	VERT. DEP 1?
193.45	193.45_
R/S	DEPART. TO 1?
47.74	47.74_
R/S	LAT. TO 1?
17.27	17.27_
R/S	STAT. 2 D?
300.0	300.0_
R/S	STAT. 2 A?
69.21	69.21_
R/S	STAT 2 I?
15.20	15.20_
R/S	FRAC. TOP?
225.0	225.0_
R/S	FRAC. BOTTOM?
225.2	225.2_
R/S	DOWN DIP AZ?
45.0	45.0_
R/S	

TOP DEPTH= 225.0000
BOTTOM DEPTH= 225.2000
CENTER DEPTH= 225.1000
TRUE DEPTH= 217.6900
TRUE DEPARTURE=53.8609
TRUE LATITUDE= 19.4989
DIP= 39.0124
DIP DIRECTION= 329.0504
STRIKE= 239.0504

SAME STAT.?   PROMPT FOR NEXT FRACTURE

N	N_
R/S	STA 2 NOW 1?
Y	Y_
R/S	STAT. 2 D?
400.0	400.0
R/S	STAT. 2 A?
71.01	71.01_
R/S	STAT. 2 I?
15.35	15.35_
R/S	FRAC. TOP?
376.0	376.0_
R/S	FRAC. BOTTOM?
406.0	406.0_
R/S	DOWN DIP AZ?
231.30	231.30_
R/S	

```
TOP DEPTH= 376.0000
BOTTOM DEPTH= 406.0000
CENTER DEPTH= 391.0000
TRUE DEPTH= 377.6799
TRUE DEPARTURE=95.0698
TRUE LATITUDE= 34.5850
DIP= 87.0232
DIP DIRECTION= 353.2245
STRIKE= 263.2245
```

SAME STAT.?	PROMPT FOR NEXT FRACTURE. TURN THE CALCULATOR OFF AND BACK ON (THIS CLEARS ALL THE FLAGS), THEN EXECUTE RCUR INSTEAD OF MINC AND REPEAT THE ABOVE PROCEDURE. THIS YIELDS SIMILAR RESULTS:

FRACTURE	1	TOP DEPTH= 50.0000
		BOTTOM DEPTH= 51.0800
		CENTER DEPTH= 50.5400
		TRUE DEPTH= 48.9209
		TRUE DEPARTURE=12.0249
		TRUE LATITUDE= 4.0536
		DIP= 65.1360
		DIP DIRECTION= 32.3004
		STRIKE= 302.3004
FRACTURE	2	TOP DEPTH 225.0000
		BOTTOM DEPTH= 225.2000
		CENTER DEPTH= 225.1000
		TRUE DEPTH= 217.6900
		TRUE DEPARTURE=53.8609
		TRUE LATITUDE= 19.4989
		DIP= 39.0124
		DIP DIRECTION= 329.0504
		STRIKE= 239.0504
FRACTURE	3	TOP DEPTH= 376.0000
		BOTTOM DEPTH= 406.0000
		CENTER DEPTH= 391.0000
		TRUE DEPTH= 377.6795
		TRUE DEPARTURE=95.0711
		TRUE LATITUDE= 34.5860
		DIP= 87.0232
		DIP DIRECTION= 353.2245
		STRIKE= 263.2245

FORTRAN PROGRAMS

Two Fortran programs were written for a Digital Equipment Corporation PDP 11/34 computer. The first program is the simpler version that requires only mimimum data to correct the orientation of a single fracture. The second program uses different hole-survey methods; it was written to reorient many fractures in one well. All parameters are entered in the same format as the calculator program; however, the output is reported only to the nearest degree. The single-fracture version is listed in table 3 (Supplemental data section); the single-well version is listed in table 4 (Supplemental data section). Variable names used in the Fortran programs, with their corresponding definitions, are listed in table 5 (Supplemental data section).

The single-fracture version requires data for eight paramters; magnetic declination, magnetic inclination, hole diameter, hole azimuth, hole inclination, measured depth to fracture top, measured depth to fracture bottom, and apparent down-dip azimuth of fracture. This version reports both the orientation of the fracture corrected for the attitude of the hole, and the orientation of the fracture corrected for both the attitude of the hole and the magnetic effect.

The single-well version of the Fortran program needs similar input. Documentation at the beginning of the program listing describes the format under which input data needs to be entered. When data are entered for the single-well version, care needs to be taken to not enter a fracture at or above the first station. For example, if a fracture centered at 0.0 was entered between line 160 and 170, in the single-well version, this entry would cause the program to stick in an infinite loop. Care also needs to be taken when the hole survey indicates no change in hole direction or inclination for a given segment, as indicated by equations 8 through 10; this would cause a division by zero. Examples of both versions follow.

Example 3--Single-Fracture Version

Note that input to this program is the same as input to the first example in the hand-held-calculator section. Therefore, the first set of answers is the same as those obtained with that program; however the second set shows the large difference in answers obtained when the magnetic effect is considered.

```
RUN DL1:SHORT

MAGNETIC DECLINATION?
   DEGREES  (NEGATIVE FOR WEST):  0.
   MINUTES: 00.
   SECONDS: 00.
```

```
MAGNETIC INCLINATION?
   DEGREES:  67.
   MINUTES:  00.
   SECONDS:  00.

HOLE DIAMETER?  0.25

HOLE AZIMUTH?
   DEGREES:  270.
   MINUTES:  00.
   SECONDS:  00.

HOLE INCLINATION?
   DEGREES:  30.
   MINUTES:  00.
   SECONDS:  00.

MEASURED DEPTH TO FRACTURE TOP?
(IN SAME UNITS AS DIAMETER):  100.00

MEASURED DEPTH TO FRACTURE BOTTOM?  100.25

DOWN DIP AZIMUTH OF FRACTURE?
   DEGREES:  90.
   MINUTES:  00.
   SECONDS:  00.

WITHOUT VERTICAL INCLINATION CORRECTION:
 TOP        BOTTOM     STRIKE     DIP        DOWN DIP AZIMUTH

100.00      100.25       0.       75.           90.

WITH VERTICAL INCLINATION CORRECTION:
 TOP        BOTTOM     STRIKE     DIP        DOWN DIP AZIMUTH

100.00      100.25      35.       68.          125.
TT5 -- STOP
```

Example 4--Single-Well Version

In this example, the second Fortran program is used. An example of the input file that needs to be created prior to running the program follows. A simplified explanation of the input is on the right. An explanation of the input parameters is given in the beginning of table 4 (Supplemental data section).

Input data:

```
Line
No.

10        0.0000 0000.0    0.000
20      0.0      0000000  0000000
30      200.0    1633900  151500
40      299.0000 1642200  152300
50      499.0000 1684200  154300
60      600.0000 1695300  162100
70      800.0000 1732700  172600
80      899.0000 1760400  175200
90      984.0000 1783900  182500
100     1099.000 1811000  190800
110     1152.000 1811800  193200
120     1201.000 1815600  194800
130     1250.000 1820400  201000
140     1850.000 1874100  225700
150     1900.000 1870600  232300
160     -1.0
170     299.00   299.00
180     499.00   499.00
190     600.00   600.00
200     800.00   800.00
210     899.00   899.00
220     984.00   984.00
230     1099.00  1099.00
240     1152.00  1152.00
250     1201.00  1201.00
260     1250.00  1250.00
270     1850.00  1850.00
280     1900.00  1900.00
290     214.40   214.79  74.0
300     214.40   214.79  63.0
310     1098.31  1098.79 133.
320     1132.23  1132.84 140.
330     1132.23  1132.84 132.
340     1233.12  1233.32 160.
350     1868.68  1868.94 172.
360     1868.34  1868.72 151.
370     -1.0
```

Line 10 contains the true depth, true departure, and true latitude of the first station.

Line 20 contains the depth measured along the borehole, the azimuth, and the borehole inclination at station 1.

Lines 30 to 150 contain the remaining station data, as in line 20.

Line 160 indicates the end of the station data with a -1.

Lines 170 to 360 contain fracture data. The first value indicates the depth measured along the borehole to the top of the fracture; the second value indicates the depth measured along the borehole to the bottom of the fracture. Note that if these first two values are the same, there is no third value; this is because the fracture is horizontal with respect to the hole. The third value indicates the down-dip azimuth of the fracture.

Line 370 indicates the end of the file.

The following are two options of the program with the input data given on page 29. A copy of the program's output for each option follows. Note that decimals need to be entered with all responses except for the hole-survey method and the integer number of pages.

Option 1:

```
RUN ROMCUR

HOLE SURVEY METHOD?
   ENTER 1 FOR RADIUS OF CURVATURE
         2 FOR MINIMUM CURVATURE OR
         3 FOR TANGENTIAL:  1

HOLE NAME? URL 1

MAGNETIC DECLINATION:
   DEGREES  (NEGATIVE FOR WEST):  7.
   MINUTES:  50.
   SECONDS:  00.

DO YOU WISH TO INCLUDE THETA?  (ENTER 1 FOR YES OR 2 FOR NO) 1

MAGNETIC INCLINATION?
   DEGREES:  77.
   MINUTES:  00.
   SECONDS:  00.

HOW MANY LINES PER PAGE (ENTER INTEGER)? 66

HOLE DIAMETER? (ENTER 0. IF VARIABLE) 0.25
```

Option 2:

```
RUN ROMCUR

HOLE SURVEY METHOD?
   ENTER 1 FOR RADIUS OF CURVATURE,
         2 FOR MINIMUM CURVATURE OR
         3 FOR TANGENTIAL:  2

HOLE NAME? URL 1

MAGNETIC DECLINATION?
   DEGREES  (NEGATIVE FOR WEST):  7.
   MINUTES:  50.
   SECONDS:  00.

DO YOU WISH TO INCLUDE THETA?  (ENTER 1 FOR YES OR 2 FOR NO) 2

HOW MANY LINES PER PAGE (ENTER INTEGER)? 66

HOLE DIAMETER? (ENTER 0. IF VARIABLE) 0.25
```

Option 1 Output

HOLE NAME: URL 1 'RADIUS OF CURVATURE' MAG. DEC. = 7. 50. 0. MAG. INC. = 77. 0. 0. PG 1

MEASURED DEPTH TO FRACTURE			COORDINATES OF FRACTURE CENTER			TRUE ORIENTATION OF FRACTURE		
CENTER	TOP	BOTTOM	TRUE DEPTH	DEPARTURE + FOR EAST	LATITUDE + FOR NORTH	STRIKE IN DEGREES	DIP IN DEGREES	DOWN DIP DIRECTION
299.00	299.00	299.00	293.13	25.36	-22.53	74.	15.	344.
499.00	499.00	499.00	485.81	37.85	-74.65	79.	16.	349.
600.00	600.00	600.00	582.88	43.03	-102.06	80.	16.	350.
800.00	800.00	800.00	774.25	51.46	-159.55	83.	18.	353.
899.00	899.00	899.00	868.59	54.20	-189.44	86.	18.	356.
984.00	984.00	984.00	949.36	55.42	-215.88	89.	19.	359.
1099.00	1099.00	1099.00	1058.24	55.48	-252.89	91.	19.	1.
1152.00	1152.00	1152.00	1108.25	55.10	-270.43	91.	20.	1.
1201.00	1201.00	1201.00	1154.39	54.63	-286.91	92.	20.	2.
1250.00	1250.00	1250.00	1200.44	54.05	-303.65	92.	20.	2.
1850.00	1850.00	1850.00	1758.42	35.32	-523.21	98.	23.	8.
1900.00	1900.00	1900.00	1804.38	32.79	-542.72	97.	23.	7.
214.60	214.40	214.79	211.73	19.23	-1.08	150.	60.	60.
214.60	214.40	214.79	211.73	19.23	-1.08	140.	63.	50.
1098.55	1098.31	1098.79	1057.82	55.48	-252.74	37.	50.	127.
1132.54	1132.23	1132.84	1089.90	55.24	-263.95	46.	53.	136.
1132.54	1132.23	1132.84	1089.90	55.24	-263.95	38.	55.	128.
1233.22	1233.12	1233.32	1184.69	54.26	-297.89	59.	21.	149.
1868.81	1868.68	1868.94	1775.73	34.35	-530.51	83.	24.	173.
1868.53	1868.34	1868.72	1775.47	34.37	-530.40	56.	38.	146.

Option 2 Output

HOLE NAME: URL 1 'MINIMUM CURVATURE' MAG. DEC. = 7. 50. 0. MAGNETIC EFFECT EXCLUDED PG 1

MEASURED DEPTH TO FRACTURE			COORDINATES OF FRACTURE CENTER			TRUE ORIENTATION OF FRACTURE		
CENTER	TOP	BOTTOM	TRUE DEPTH	DEPARTURE + FOR EAST	LATITUDE + FOR NORTH	STRIKE IN DEGREES	DIP IN DEGREES	DOWN DIP DIRECTION
299.00	299.00	299.00	293.13	14.65	-50.53	74.	15.	344.
499.00	499.00	499.00	485.82	27.12	-102.64	79.	16.	349.
600.00	600.00	600.00	582.89	32.30	-130.05	80.	16.	350.
800.00	800.00	800.00	774.26	40.66	-187.53	83.	18.	353.
899.00	899.00	899.00	868.60	43.39	-217.41	86.	18.	356.
984.00	984.00	984.00	949.38	44.61	-243.84	89.	19.	359.
1099.00	1099.00	1099.00	1058.26	44.65	-280.85	91.	19.	1.
1152.00	1152.00	1152.00	1108.27	44.27	-298.39	91.	20.	1.
1201.00	1201.00	1201.00	1154.41	43.81	-314.87	92.	20.	2.
1250.00	1250.00	1250.00	1200.46	43.22	-331.61	92.	20.	2.
1850.00	1850.00	1850.00	1758.49	23.85	-550.96	98.	23.	8.
1900.00	1900.00	1900.00	1804.46	21.32	-570.47	97.	23.	7.
214.60	214.40	214.79	211.73	8.53	-29.08	161.	57.	71.
214.60	214.40	214.79	211.73	8.53	-29.08	151.	60.	61.
1098.55	1098.31	1098.79	1057.83	44.65	-280.70	41.	49.	131.
1132.54	1132.23	1132.84	1089.92	44.42	-291.91	50.	52.	140.
1132.54	1132.23	1132.84	1089.92	44.42	-291.91	41.	54.	131.
1233.22	1233.12	1233.32	1184.70	43.43	-325.85	64.	20.	154.
1868.81	1868.68	1868.94	1775.80	22.88	-558.26	83.	24.	173.
1868.53	1868.34	1868.72	1775.55	22.89	-558.15	56.	38.	146.

STEREOGRAPHIC SOLUTIONS

The orientation of a fracture also can be corrected by using the angle theta (fig. 8) and a stereonet. It is assumed that the reader is familiar with stereographic projections on a Wulff net (Goodman, 1976). The following plots use the lower hemisphere unless otherwise specified. Note that the position of the planes in the following illustrations are sometimes shown after the overlying trace paper has been rotated to a second position. This section will illustrate the stereographic method by using the examples in the previous program sections.

Stereographic Solution of a Simple-Dip Increase

The solution of the example given in figure 10 is stereographically solved in figure 11. The bottom one-half of a plane perpendicular to the hole axis (henceforth referred to as the hole-reference plane) at the position that the fracture intersects the borehole is shown in figure 11(a). This hole-reference plane is then rotated out to the edge of the net, as indicated by the dashed arrows in figure 11(a). The apparent strike and dip of the fracture is then plotted on the net, as shown in figure 11(b). Then, both the fracture and the hole-reference plane are rotated back to the original position in figure 11(a), which is shown in figure 11(c) by the dashed arrows. The new position of the fracture plane is shown with a dotted line. This new plane has the proper dip and strike, as shown in figure 11(d).

Stereographic Solution of a Rotation Off the Net

The procedure to be used when the apparent-fracture plane is rotated off the net is shown in figure 12. Using the same hole orientation as described in figure 11(a), the hole-reference plane is plotted and rotated out to the periphery in figure 12(a). A rotation problem occurs, as illustrated in figure 12(b), when the hole-reference plane and a fracture (apparent attitude N 20° E/12° W) rotate back to the original position. The fracture rotates off the net. This occurs because the stereographic-projection technique uses only the lower hemisphere, and, therefore, the lower one-half of the fracture plane. By plotting the upper one-half of the fracture plane, rotation can be successfully accomplished. The upper and lower halves of the apparent-fracture plane (a plane representing the fracture with an apparent attitude) is shown in figure 12(c). The movement of a point A on the upper one-half of the apparent-fracture plane, as it is rotated with the hole-reference plane back to its correct position is depicted in figure 12(d). First, the point is rotated down 20° from the upper one-half of the projection to the edge, A1. Next, it is rotated the remaining 10° in the normal manner on the lower one-half of the projection to the point A2.

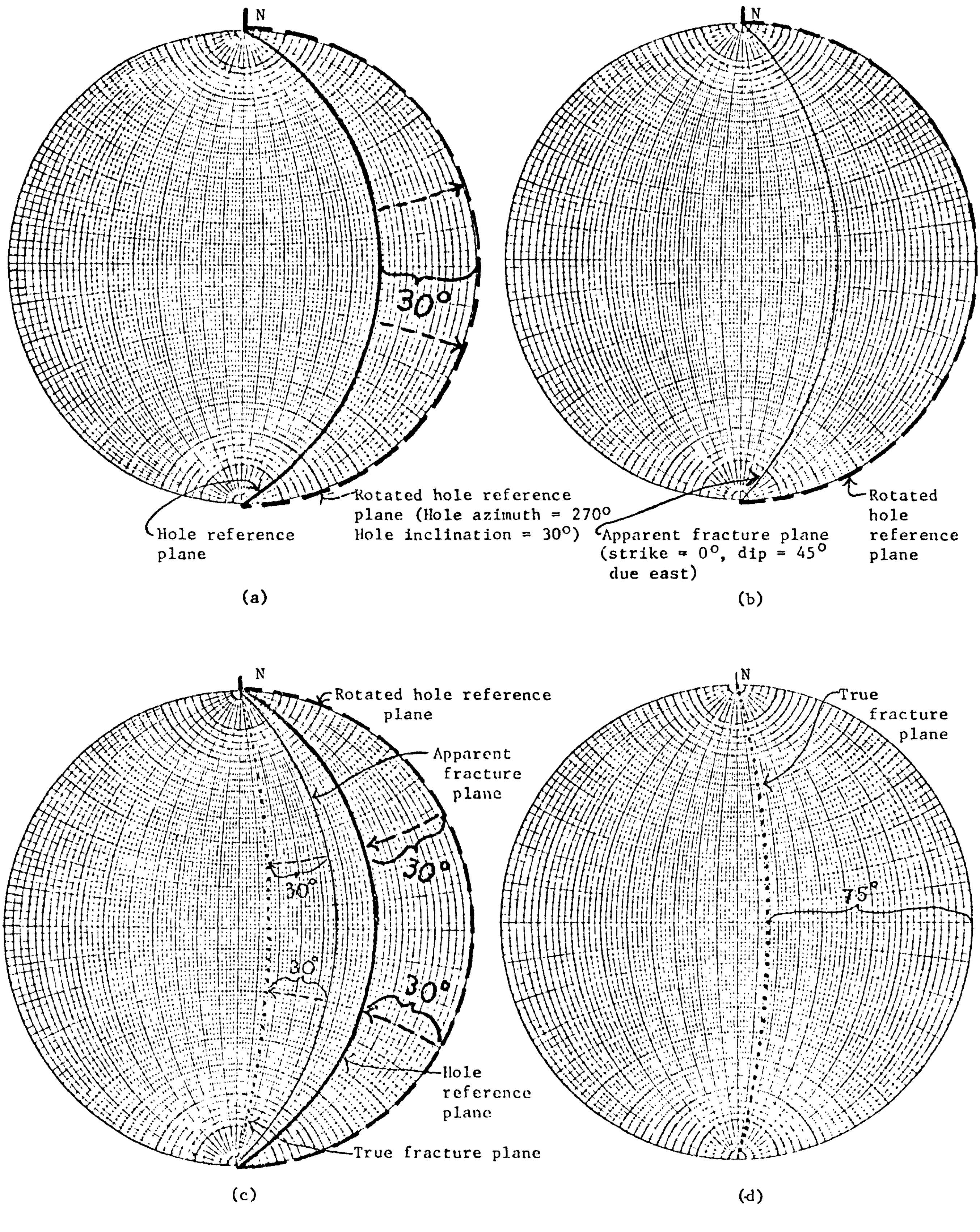


Figure 11.--Stereographic projection 1--Dip increase.

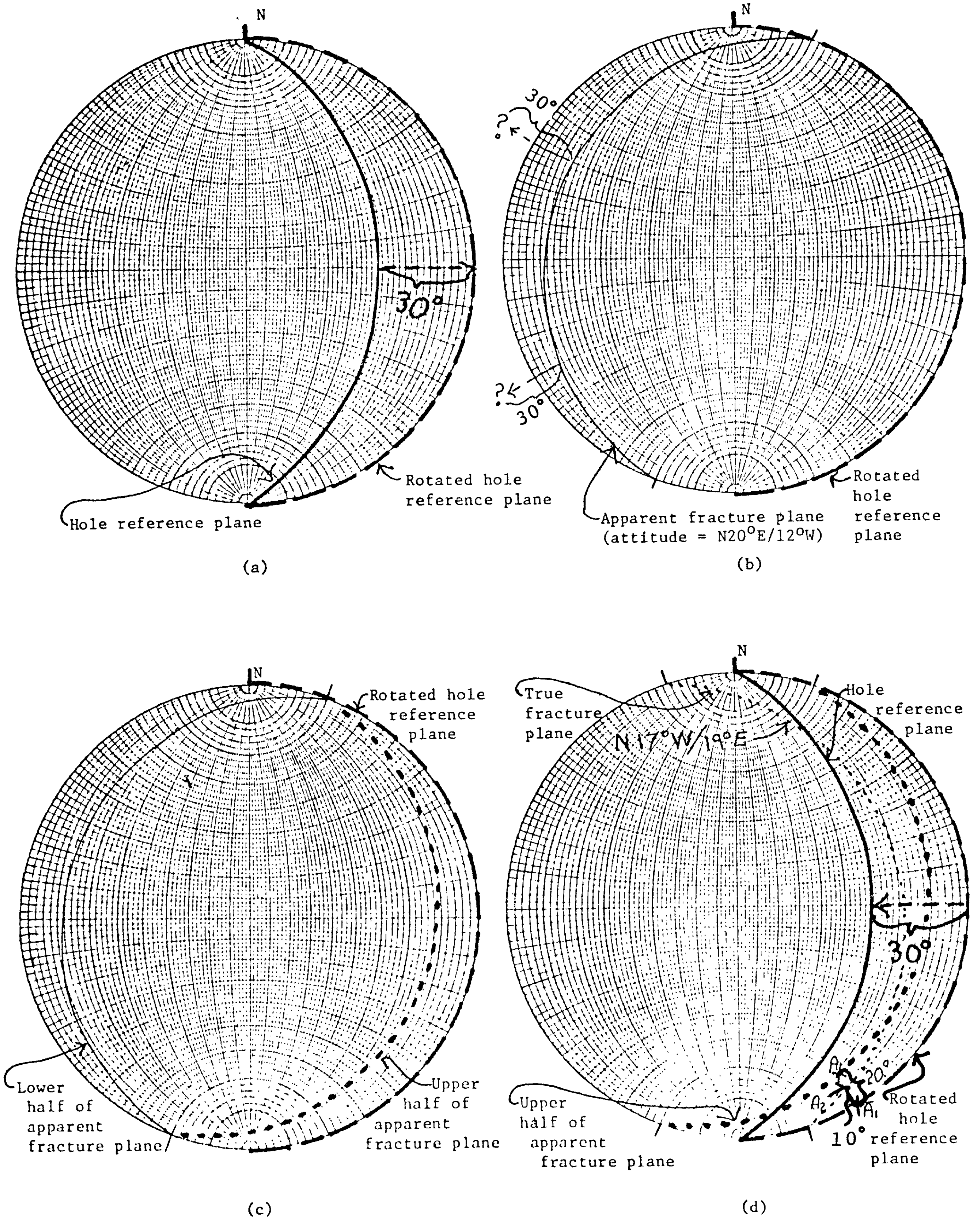


Figure 12.--Stereographic projection 2--Rotation off net.

Stereographic Solution Including a Magnetic-Declination Angle

The effect of a +20° magnetic declination on a fracture, with an apparent attitude of N 60° E/45° S (the attitude of the fracture is referenced from magnetic north), is represented in figure 13. The hole has an azimuth of 60° and an inclination of 30°. The hole-reference plane and a rotation axis indicated by the line CD is shown in figure 13(a). The rotation axis corresponds to the strike of the hole-reference plane. The magnetic-north marker (MN) is plotted 20° clockwise from north.

Because the magnetic-north marker does not lie along the axis of rotation, a new rotated magnetic-north marker needs to be determined. This is done by finding the point at which the hole-reference plane intersects the magnetic north-south line. The magnetic-north marker is alined with the vertical-stereonet line in figure 13(b). The point A is the intersection point of the north-south line and the hole-reference plane. A line from the center of the stereonet to the point A indicates the magnetic-south direction in the hole-reference plane.

The rotation axis is alined with the vertical-stereonet line, as shown in figure 13(c). The hole-reference plane is rotated 30° out to the edge, and the point A is rotated out to the point A1. This new point, A1, represents the rotated magnetic-south marker (MSr). The rotated magnetic-north marker (MNr) is 180° from the magnetic-south marker.

The rotated magnetic-north marker is alined with the vertical-stereonet line in figure 13(d). From this point, the fracture (apparent attitude N 60° E/45° S) is plotted. The rotation axis is alined with the vertical-stereonet line; the rotated hole-reference plane and the apparent-fracture plane are rotated back 30° to their true positions in figure 13(e). The fracture plane is shown to have a true attitude of S 47° E/62° W in figure 13(f).

Stereographic Solution Including a Magnetic-Inclination Angle

The rotation of a fracture (apparent attitude S 10° W/45° N) found in a hole with a 50° azimuth and a 30° inclination is shown in figure 14. The magnetic inclination is 67°. The hole-reference plane, rotation axis (CD), the true-north marker (N), and the magnetic-north marker (MN) are shown in figure 14(a). The magnetic-north marker is alined with the vertical-stereonet line, and the intersection of this line with the hole-reference plane is marked by the point A. This point (A) and the plane are rotated out 30° to the edge in figure 14(b). The point A1 establishes the rotated magnetic-south marker (MSr) and its complement, the rotated magnetic-north marker (MNr).

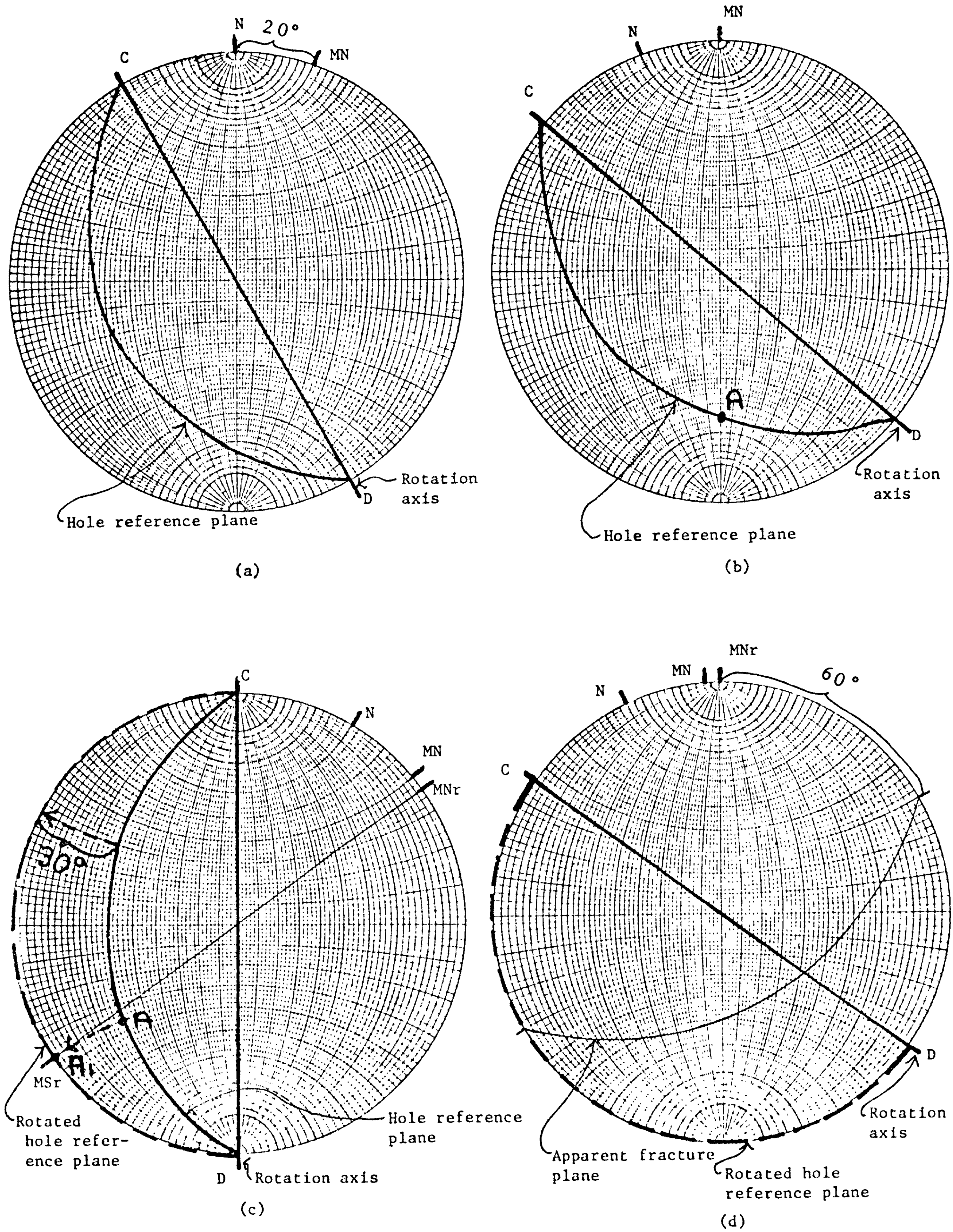


Figure 13.--Stereographic projection 3--Including magnetic-declination angle.

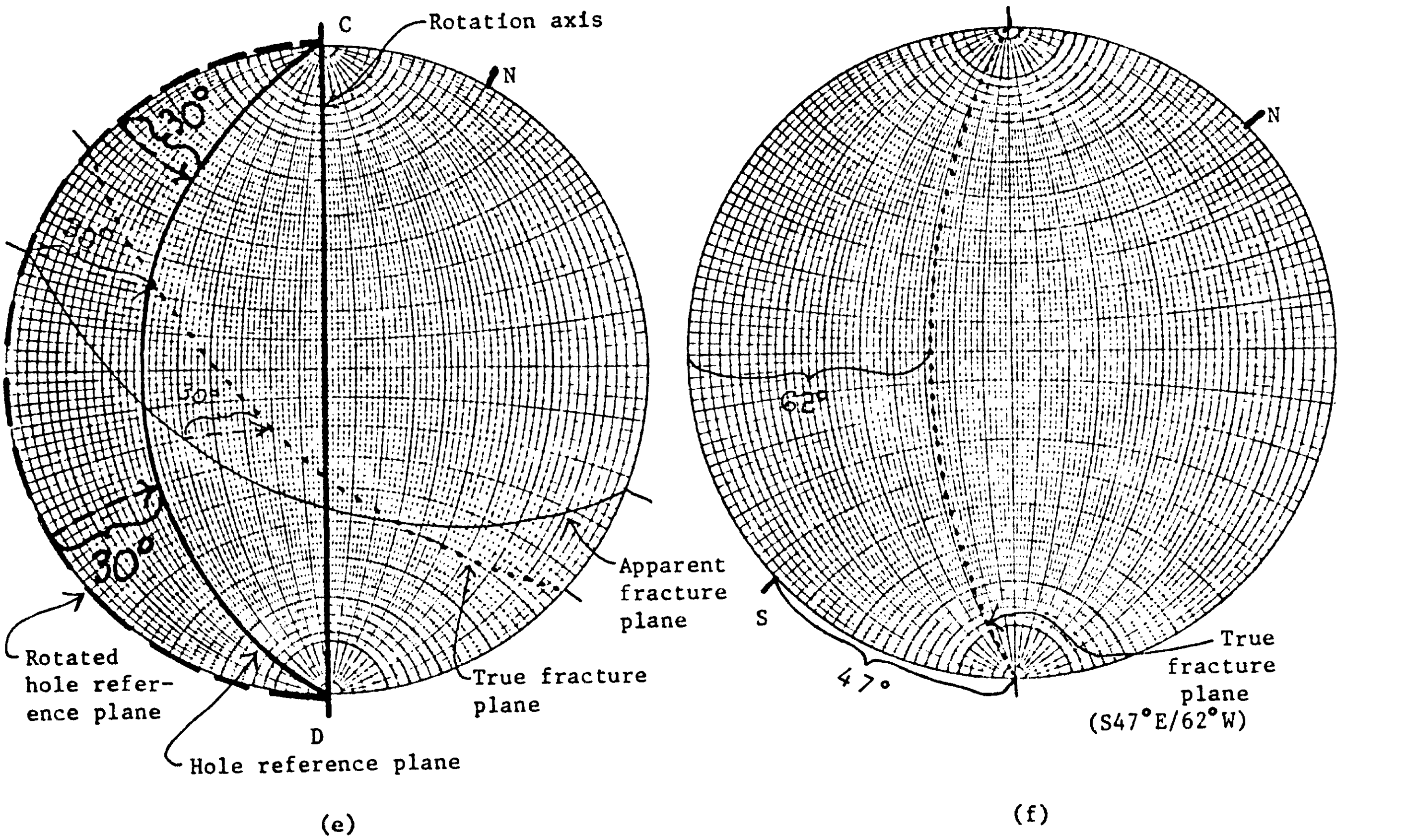


Figure 13.--Stereographic projection 3--Including magnetic-declination angle--Continued.

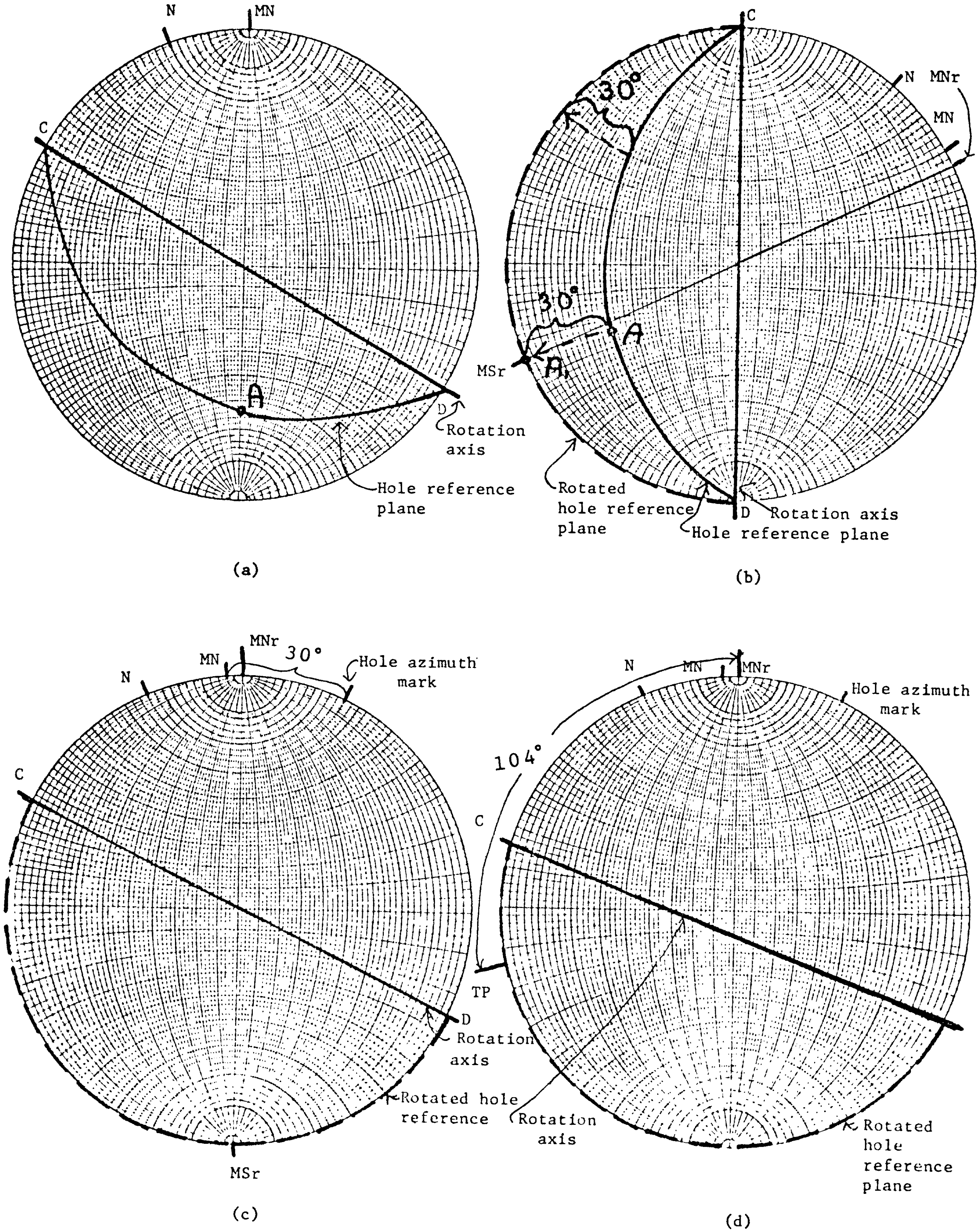


Figure 14.--Stereographic projection 4--Including magnetic-inclination angle.

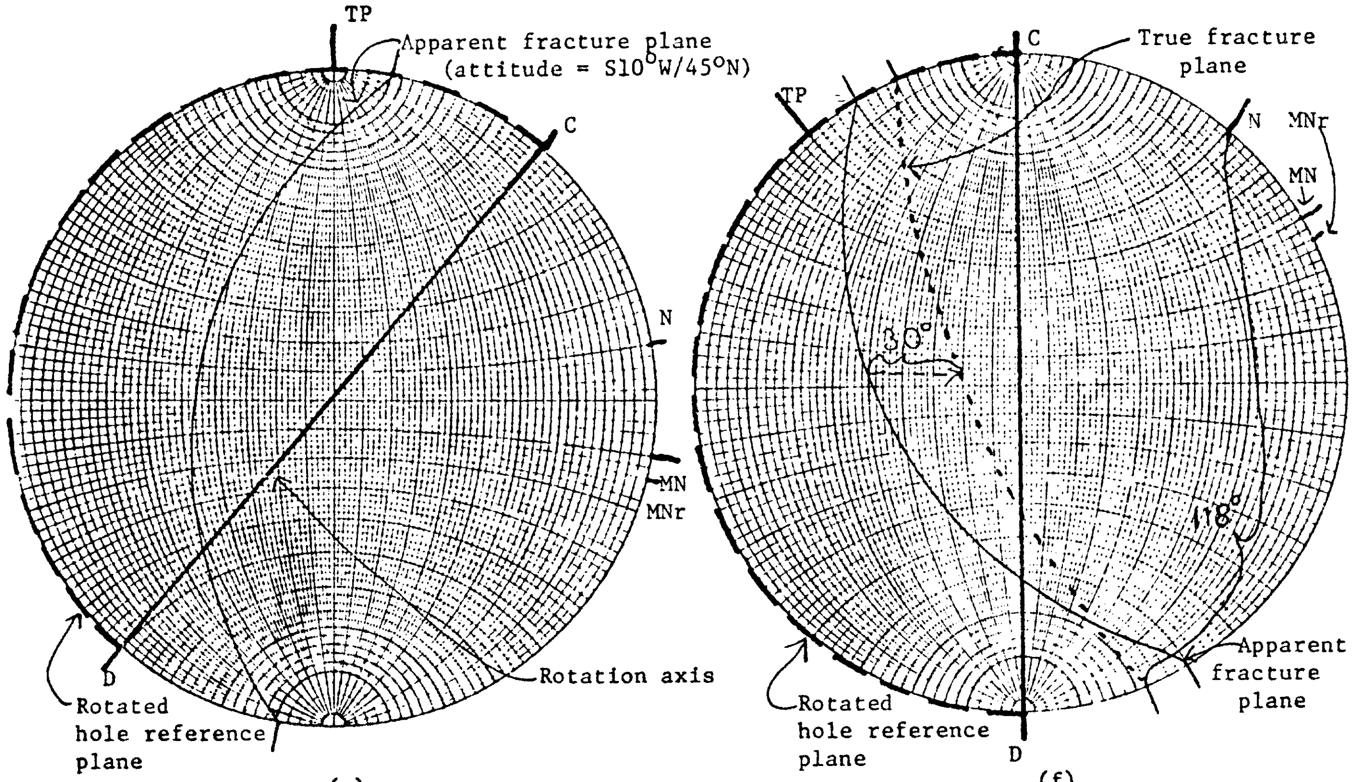


Figure 14.--Stereographic projection 4--Including magnetic-inclination angle--Continued.

The 30° separation between the hole-azimuth marker (50° from N) and the magnetic-north marker is illustrated in figure 14(c). This clockwise distance, in degrees from magnetic-north to the hole-azimuth marker, is the value of the hole azimuth to be used in table 6 (Supplemental data section). In this table, the theta-correction values in an area with a magnetic inclination of 67° for hole inclination varying from 5° to 85° are indicated. A short calculator program to calculate the absolute value of theta for any hole azimuth (referenced from magnetic north) and any inclination is listed in table 7 (Supplemental data section). This program does not supply the correct sign; it needs to be obtained as explained in the section on magnetic effect. The formula used to calculate theta is given in equation 28. The program reports theta in degrees--not degrees, minutes, and seconds. A 30° hole azimuth and a 30° hole inclination yields a -104° theta correction (the negative indicates counterclockwise direction) in figure 14(d). The position of the triggering point (TP) also is indicated in figure 14(d). It is located theta degrees from MNr; in this case, 104° counterclockwise from MNr.

The apparent-fracture plane is plotted after alining the triggering point with the vertical-stereonet line in figure 14(e). The rotation axis is realined with the vertical-stereonet line in figure 14(f). The rotated hole-reference plane and apparent-fracture plane are then rotated back 30° to their true positions. The fracture has a true attitude of N 62° W/72° S.

CONCLUSIONS

The acoustic televiewer is a logging device that produces images of fractures that intersect a borehole. The attitude of planar fractures seen with the acoustic televiewer can be corrected for hole geometry and magnetic-field effects. Correcting the fractures for hole geometry requires only a hole survey. An additional correction for the magnetic effect requires knowledge of the inclination of the Earth's magnetic field at the logging site. Maps showing the magnetic inclination and declination in the United States can be purchased from the U.S. Geological Survey. The corrections due to the magnetic field can be as large as 180°. Tests were conducted to verify the magnetic-effect correction. These tests indicated an accuracy of corrected fracture attitude of 2.8 percent. The also illustrates how to correct the orientation of fractures through stereographic projection.

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SUPPLEMENTAL DATA SECTION

Table 1.--*Storage-register assignments*

00	Calculation register - variable content.
01	Hole name.
02	Magnetic declination.
03	Hole diameter.
04	Hole azimuth.
05	Hole dip.
06	Depth (as measured along the hole) to the top of the sinusoidal fracture.
07	Depth (as measured along the hole) to the bottom of the sinusoidal fracture.
08	Depth (calculated from 06 and 07 above) to the center of the sinusoidal fracture.
09	Positive difference in depth between top and bottom of the fracture = h.
10	Apparent fracture dip (calculated from 09 and 03 above) = P.
11	Apparent fracture strike = apparent down dip azimuth -90° = K.
12	Computational factor = $\sqrt{\tan^2(05) + \cos^2(04)}$ = B.
13	Directional cosine = αf.
14	Directional cosine = βf.
15	Directional cosine = γf.
16	Well depth to station 1 = D1.
17	Azimuth at station 1 = A1.
18	Inclination at station 1 = I1.
19	True vertical depth to station 1.
20	True departure to station 1.
21	True latitude to station 1.
22	Well depth to station 2 = D2.
23	Azimuth to station 2 = A2.
24	Inclination at station 2 = I2.
25	Difference in well depth between stations (station 2-station 1) = ΔD.
26	Difference in well azimuth between stations (station 2-station 1) = ΔA.
27	Difference in well inclination between stations (station 2-station 2) = ΔI.
28	True vertical depth to center of fracture = ΔtV.
29	True departure to center of fracture = ΔtE.
30	True latitude to center of fracture = ΔtN.
31	New inclination angle at fracture center.
32	New or old dogleg angle for minimum curvature method.
33	Calculation register - variable content - usually = RF.
34	Difference in true depth between stations = ΔV.
35	Difference in true latitude between stations = ΔN.
36	Difference in true departure between stations = ΔE.
37	Magnetic inclination angle = V.
38	Amplitude of the vector Q.
39	Amplitude of the vector R.
40	Angle between vector R and the vector N = θ.

Table 2.--*Hand-held-calculator program listing*

```
LBL "TANG"
XEQ 01
"HOLE AZIMUTH?"
PROMPT
HR
STO 04
LBL 15
"INC.?"
PROMPT
HR
STO 31
CHS
90
+
STO 05
LBL 03
ADV
XEQ 04
FS?C 11
XEQ 94
RCL 08
RCL 31
COS
*
STO 28
RCL 31
SIN
RCL 04
COS
*
RCL 08
*
STO 30
RCL 31
SIN
RCL 04
SIN
*
RCL 08
*
STO 29
FS? 12
GTO 60
RCL 02
ST- 04
FS? 17
XEQ D
XEQ "R"
GTO 03
LBL 01
AON
"HOLE NAME? "
PROMPT
ASTO 01
"HOLE NAME= "
ARCL 01
AVIEW
AOFF
ADV
"DECL? +FOR E"
PROMPT
HR
STO 02
"N"
ASTO Y
AON
"WITH THETA?"
PROMPT
ASTO X
AOFF
X=Y?
GTO 16
SF 17
"MAG. INC.?"
PROMPT
```

Table 2.--*Hand-held-calculator program listing*--Continued

76	HR	101	/	126	"YOU GOOFED"
77	STO 37	102	RCL 06	127	AVIEW
78	LBL 16	103	+	128	RTN
79	"HOLE DIA?"	104	STO 08	129	LBL 13
80	PROMPT	105	RCL 09	130	XEQ 12
81	STO 03	106	RCL 03	131	GTO 04
82	X<=0?	107	/	132	LBL 14
83	XEQ 17	108	ATAN	133	"YOU DO IT"
84	RTN	109	STO 10	134	AVIEW
85	LBL 04	110	"DOWN DIP AZ?"	135	BEEP
86	TONE 1	111	PROMPT	136	PSE
87	"FRAC. TOP?"	112	HR	137	GTO 70
88	PROMPT	113	90.	138	LBL 17
89	STO 06	114	-	139	XEQ 12
90	"FRAC. BOTTOM?"	115	X<0?	140	GTO 16
91	PROMPT	116	XEQ 92	141	LBL 94
92	STO 07	117	STO 11	142	SF 12
93	-	118	RTN	143	XEQ 93
94	CHS	119	LBL 92	144	RTN
95	STO 09	120	360	145	LBL 93
96	X<0?	121	+	146	RCL 31
97	XEQ 13	122	RTN	147	HMS
98	X=0?	123	LBL 12	148	STO 00
99	SF 11	124	SF 20	149	"DIP= "
100	2	125	BEEP	150	ARCL 00

Table 2.--*Hand-held-calculator program listing*--Continued

```
AVIEW
RCL 04
180
+
XEQ 91
HMS
STO 00
"DIP DIRECTION= "
ARCL 00
AVIEW
RCL 00
90
+
XEQ 91
STO 00
"STRIKE= "
ARCL 00
AVIEW
RTN
LBL 91
360.0000
X<>Y
X<Y?
RTN
X<>Y
-
RTN
LBL "R"
RCL 31
X=0?
GTO 14
SF 24
XEQ B
RCL 11
COS
RCL 04
SIN
*
RCL 04
COS
*
RCL 05
COS
*
RCL 05
TAN
RCL 11
SIN
*
+
RCL 10
SIN
*
RCL 12
/
CHS
RCL 10
COS
RCL 04
COS
*
RCL 05
COS
*
-
STO 13
RCL 10
COS
RCL 04
SIN
RCL 05
COS
*
*
CHS
```

Table 2.--*Hand-held-calculator program listing*--Continued

```
RCL 10
SIN
RCL 11
COS
*
RCL 05
COS
*
RCL 12
*
+
STO 14
RCL 11
COS
RCL 04
SIN
RCL 05
SIN
*
*
CHS
RCL 11
SIN
RCL 04
COS
*
+
RCL 10
SIN
*
RCL 12
/
RCL 05
SIN
RCL 10
COS
*
-
STO 15
CF 24
"TOP DEPTH= "
ARCL 06
AVEIW
"BOTTOM DEPTH= "
ARCL 07
AVIEW
LBL 60
"CENTER DEPTH= "
ARCL 08
AVIEW
"TRUE DEPTH= "
ARCL 28
AVIEW
"TRUE DEPARTURE="
ARCL 29
AVIEW
"TRUE LATITUDE= "
ARCL 30
AVIEW
FS?C 12
GTO 03
FS?C 13
GTO 96
FS?C 14
GTO 98
RCL 15
X<0?
GTO 37
RCL 13
CHS
STO 13
RCL 14
CHS
STO 14
RCL 15
```

Table 2.--*Hand-held-calculator program listing*--Continued

301	CHS	326	RCL 02	351	HMS
302	STO 15	327	+	352	STO 00
303	GTO 37	328	STO 00	353	"DIP DIRECTION= "
304	LBL 70	329	X<0?	354	ARCL 00
305	RTN	330	XEQ 56	355	AVIEW
306	LBL 37	331	STO 00	356	RCL 00
307	RCL 14	332	360	357	90
308	X=0?	333	X<Y?	358	-
309	GTO 51	334	GTO 58	359	X<0?
310	SF 25	335	CLX	360	XEQ 56
311	RCL 14	336	LBL 66	361	"STRIKE= "
312	RCL 13	337	RCL 15	362	ARCL X
313	/	338	ACOS	363	AVIEW
314	FC?C 25	339	CHS	364	GTO 70
315	GTO 38	340	180	365	LBL 38
316	ATAN	341	+	366	RCL 13
317	STO 00	342	.5	367	X=0?
318	X<0?	343	X<>Y	368	GTO 53
319	XEQ 57	344	X<Y?	369	SF 24
320	LBL 50	345	GTO 52	370	RCL 14
321	RCL 14	346	HMS	371	RCL 13
322	X<0?	347	"DIP= "	372	/
323	XEQ 57	348	ARCL X	373	CF 24
324	LBL 63	349	AVIEW	374	ATAN
325	RCL 00	350	RCL 00	375	STO 00

```
X<0?
XEQ 57
GTO 50
LBL 51
RCL 13
X=0?
GTO 52
X<0?
GTO 55
0
STO 00
GTO 63
LBL 52
"DIP= 0.0000"
AVIEW
GTO 70
LBL 55
180
STOP 00
GTO 63
LBL 53
RCL 14
X<0?
GTO 54
90
STO 00
GTO 63
LBL 54
270
STO 00
GTO 63
LBL 56
360
+
RTN
LBL 57
RCL 00
180
ST+ 00
RTN
LBL 58
360
ST- 00
GTO 66
LBL "MINC"
XEQ 01
LBL 08
XEQ 05
LBL 09
ADV
XEQ 04
XEQ 07
FS?C 20
GTO 08
RCL 26
COS
CHS
1.0
+
RCL 24
SIN
*
RCL 18
SIN
*
CHS
RCL 27
COS
+
ACOS
STO 32
XEQ 18
RCL 24
STO 31
RCL 23
```

```
451 STO 04
452 XEQ 19
453 RCL 25
454 *
455 STO 34
456 XEQ 20
457 RCL 25
458 *
459 STO 35
460 XEQ 21
461 RCL 25
462 *
463 STO 36
464 RCL 32
465 RCL 08
466 RCL 16
467 -
468 RCL 25
469 /
470 *
471 STO 32
472 RCL 08
473 RCL 16
474 -
475 RCL 25
476 /
477 RCL 27
478 *
479 RCL 18
480 +
481 STO 31
482 CHS
483 90
484 +
485 STO 05
486 RCL 08
487 RCL 16
488 -
489 RCL 25
490 /
491 RCL 26
492 *
493 RCL 17
494 +
495 STO 04
496 XEQ 18
497 XEQ 19
498 RCL 08
499 RCL 16
500 -
501 *
502 RCL 19
503 +
504 STO 28
505 XEQ 20
506 RCL 08
507 RCL 16
508 -
509 *
510 RCL 21
511 +
512 STO 30
513 XEQ 21
514 RCL 08
515 RCL 16
516 -
517 *
518 RCL 20
519 +
520 STO 29
521 FS?C 11
522 GTO 95
523 RCL 02
524 ST- 04
525 FS? 17
```

```
526  XEQ D
527  XEQ "R"
528  LBL 96
529  "N"
530  ASTO Y
531  AON
532  "SAME STAT.?"
533  PROMPT
534  ASTO X
535  X=Y?
536  GTO 25
537  AOFF
538  STO 09
539  LBL 18
540  RCL 32
541  2
542  /
543  TAN
544  2
545  *
546  RCL 32
547  D-R
548  /
549  STO 33
550  RTN
551  LBL 19
552  RCL 31
553  COS
554  RCL 18
555  COS
556  +
557  RCL 33
558  *
559  2
560  /
561  RTN
562  LBL 20
563  RCL 31
564  SIN
565  RCL 04
566  COS
567  *
568  RCL 18
569  SIN
570  RCL 17
571  COS
572  *
573  +
574  RCL 33
575  *
576  2
577  /
578  RTN
579  LBL 21
580  RCL 31
581  SIN
582  RCL 04
583  SIN
584  *
585  RCL 18
586  SIN
587  RCL 17
588  SIN
589  *
590  +
591  RCL 33
592  *
593  2
594  /
595  RTN
596  LBL 25
597  XEQ 28
598  GTO 09
599  LBL 28
600  "N"
```

```
ASTO Y
"STA 2 NOW 1?
PROMPT
ASTO X
AOFF
X=Y?
GTO 08
XEQ 26
RTN
LBL 26
RCL 22
STO 16
RCL 23
STO 17
RCL 24
STO 18
RCL 34
ST+ 19
RCL 35
ST+ 21
RCL 36
ST+ 20
XEQ 27
RTN
LBL 05
"STAT. 1 D?"
PROMPT
STO 16
"STAT. 1 A?"
PROMPT
HR
STO 17
"STAT. 1 I?"
PROMPT
HR
STO 18
"VERT. DEP 1?"
PROMPT
STO 19
"DEPART. TO 1?"
PROMPT
STO 20
"LAT. TO 1?"
PROMPT
STO 21
LBL 27
"STAT. 2 D?"
PROMPT
STO 22
RCL 16
-
STO 25
"STAT. 2 A?"
PROMPT
HR
STO 23
RCL 17
-
STO 26
"STAT. 2 I?"
PROMPT
HR
STO 24
RCL 28
-
STO 27
RTN
LBL 07
RCL 22
RCL 08
X>Y?
XEQ 12
RCL 16
RCL 08
X<=Y?
```

Table 2.--*Hand-held-calculator program listing*--Continued

676	XEQ 12
677	RTN
678	LBL 95
679	SF 13
680	XEQ 93
681	GTO 60
682	LBL "RCUR"
683	XEQ 01
684	LBL 10
685	XEQ 05
686	LBL 11
687	ADV
688	XEQ 04
689	XEQ 07
690	FS?C 20
691	GTO 10
692	RCL 24
693	STO 31
694	RCL 23
695	STO 04
696	XEQ 80
697	RCL 25
698	*
699	STO 34
700	XEQ 81
701	RCL 25
702	*
703	STO 35
704	XEQ 83
705	RCL 25
706	*
707	STO 35
708	RCL 08
709	RCL 16
710	-
711	RCL 25
712	/
713	STO 33
714	RCL 27
715	D-R
716	*
717	R-D
718	RCL 18
719	+
720	STO 31
721	CHS
722	90
723	+
724	STO 05
725	RCL 33
726	RCL 26
727	D-R
728	*
929	R-D
730	RCL 17
731	+
732	STO 04
733	XEQ 80
734	RCL 08
735	RCL 16
736	-
737	STO 33
738	*
739	RCL 19
740	+
741	STO 28
742	XEQ 81
743	RCL 33
744	*
745	RCL 20
746	+
747	STO 29
748	XEQ 81
749	RCL 33
750	*

Table 2.--*Hand-held-calculator program listing*--Continued

```
751 RCL 21
752 +
753 STO 30
754 FS?C 11
755 GTO 97
756 RCL 02
757 ST- 04
758 FS? 17
759 XEQ D
760 XEQ "R"
761 LBL 98
762 "N"
763 ASTO Y
764 AON
765 "SAME STAT.?"
766 PROMPT
767 ASTO X
768 X=Y?
769 GTO 85
770 AOFF
771 GTO 11
772 LBL 80
773 RCL 31
774 SIN
775 RCL 18
776 SIN
777 -
778 RCL 31
779 RCL 18
780 -
781 D-R
782 /
783 RTN
784 LBL 81
785 XEQ 82
786 RCL 17
787 COS
788 RCL 04
789 COS
790 -
791 *
792 RTN
793 LBL 82
794 RCL 18
795 COS
796 RCL 31
797 COS
798 -
799 RCL 31
800 RCL 18
801 -
802 D-R
803 /
804 RCL 04
805 RCL 17
806 -
807 D-R
808 /
809 RTN
810 LBL 83
811 XEQ 82
812 RCL 04
813 SIN
814 RCL 17
815 SIN
816 -
817 *
818 RTN
819 LBL 86
820 "N"
821 ASTO Y
822 "STA 2 NOW 1?"
823 PROMPT
824 ASTO X
825 AOFF
```

```
X=Y?
GTO 10
XEQ 26
RTN
LBL 85
XEQ 86
GTO 11
LBL 97
SF 14
XEQ 93
GTO 60
LBL B
SF 24
RCL 04
COS
X↑2
RCL 05
TAN
X↑2
+
SQRT
STO 12
CF 24
RTN
LBL D
RCL 31
X=0?
RTN
XEQ B
RCL 37
COS
RCL 04
COS
RCL 05
COS
*
*
RCL 05
SIN
RCL 37
SIN
*
+
STO 38
1.000000000
X<=Y?
STO 38
CHS
X>Y?
STO 38
RCL 38
X↑2
CHS
1.0
+
SQRT
X=0?
GTO 77
STO 39
RCL 37
COS
RCL 05
COS
RCL 04
COS
*
RCL 38
*
-
RCL 05
TAN
*
RCL 37
SIN
RCL 05
```

Table 2.--*Hand-held-calculator program listing*--Continued

```
SIN
RCL 38
*
-
RCL 04
COS
*
-
RCL 12
/
RCL 39
/
ACOS
STO 40
180.00000
RCL 04
X<=Y?
GTO 71
RCL 11
RCL 40
+
STO 11
GTO 72
LBL 71
RCL 11
RCL 40
-
STO 11
LBL 72
360.000000
X>Y?
GTO 75
-
STO 11
GTO 73
LBL 75
0
RCL 11
X<Y?
360
+
STO 11
LBL 73
RTN
LBL 77
"FUNNY Q=0"
AVIEW
STOP
.END.
```

Table 3.--*Fortran program listing--Single-fracture version*

```
C ************* FORMAT STATEMENTS **********************************
  400   FORMAT (/,1X,' MAGNETIC DECLINATION?',/,5X,'DEGREES
     $  (NEGATIVE FOR WEST):   ',$)
  425   FORMAT (5X,'MINUTES:   ',$)
  450   FORMAT (5X,'SECONDS:   ',$)
  500   FORMAT (/,1X,' MAGNETIC INCLINATION?',/,5X,'DEGREES:   '$)
  600   FORMAT (F)
 2300   FORMAT (/,1X,' HOLE DIAMETER?  ',$)
 2380   FORMAT (/,2X,'HOLE AZIMUTH?',/,5X,'DEGREES:   ',$)
 2382   FORMAT (/,2X,'HOLE INCLINATION?',/,5X,'DEGREES:   ',$)
 2384   FORMAT (/,2X,'MEASURED DEPTH TO FRACTURE TOP?',/,1X,
     $  ' (IN SAME UNITS AS DIAMETER):   ',$)
 2386   FORMAT (/,2X,'MEASURED DEPTH TO FRACTURE BOTTOM?   ',$)
 2388   FORMAT (/,2X,'DOWN DIP AZIMUTH OF FRACTURE?',/,
     $  5X,'DEGREES:   ',$)
 2389   FORMAT (1X,/,/,1X,'WITHOUT VERTICAL INCLINATION CORRECTION:')
 2390   FORMAT (1X,/,/,1X,'WITH VERTICAL INCLINATION CORRECTION:')
 2391   FORMAT (2X,'TOP',7X,'BOTTOM',4X,'STRIKE',4X,'DIP',7X,
     $  'DOWN DIP AZIMUTH',/)
        PI=3.14159265
C ****************** INPUT OF DATA ******************************
        TYPE 400
        ACCEPT 600, DECD
        TYPE 425
        ACCEPT 600, DECM
        TYPE 450
        ACCEPT 600, DECS
        DEC=(PI/180.)*(DECD+DECM/60.+DECS/3600.)
        TYPE 500
        ACCEPT 600, RINCD
        TYPE 425
        ACCEPT 600,RINCM
        TYPE 450
        ACCEPT 600, RINCS
        RINC=(PI/180.)*(RINCD+RINCM/60.+RINCS/3600.)
        TYPE 2300
        ACCEPT 600, DIA
        TYPE 2380
        ACCEPT 600,WHAZD
        TYPE 425
        ACCEPT 600,WHAZM
        TYPE 450
        ACCEPT 600,WHAZS
        HELP=(PI/180.)*(WHAZD+(WHAZM/60.)+(WHAZS/3600.))
        HZI=HELP
        TYPE 2382
        ACCEPT 600,WHICD
        TYPE 425
        ACCEPT 600, WHICM
        TYPE 450
        ACCEPT 600, WHICS
        HINC=(WHICD+(WHICM/60.)+(WHICS/3600.))*(PI/180.)
        TYPE 2384
        ACCEPT 600, RMDEPT
        TYPE 2386
        ACCEPT 600, RMDEPB
        TYPE 2388
        ACCEPT 600,WDDAZD
        TYPE 425
        ACCEPT 600,WDDAZM
        TYPE 450
        ACCEPT 600,WDDAZS
        DIPDIR=(WDDAZD+(WDDAZM/60.)+(WDDAZS/3600.))*(PI/180.)
```

```
 2900    RMDEP=(RMDEPT+RMDEPB)/2.0
         I=1
         TYPE 2389
         TYPE 2391
         CALL ROTATE (HELP,HINC,DEC,RINC,RMDEP,RMDEPT,RMDEPB,
      $  DIPDIR,DIA,I)
         I=2
         TYPE 2390
         TYPE 2391
         CALL ROTATE (HZI,HINC,DEC,RINC,RMDEP,RMDEPT,RMDEPB,
      $  DIPDIR,DIA,I)
         STOP
         END
C ****************************************************************************
         SUBROUTINE ROTATE (AZI, CLINA, DECLIN, VERTC, DEPTHM,
      $  DEPMT, DEPMB, DDIPAZ, DIAMET, IJUDGE)
C ************************ FORMAT STATEMENTS **************************
 4300   FORMAT (2X,'ERROR DETECTED IN INPUT')
 4500   FORMAT (2X,F7.2,3X,F7.2,5X,'HORIZONTAL FRACTURE')
 4550   FORMAT (2X,F7.2,3X,F7.2,5X,F4.0,6X,'VERTICAL FRACTURE')
 4600   FORMAT (2X,'QMAG=0.0 - YOU ARE VERY FUNNY!')
 4620   FORMAT (2X,F7.2,3X,F7.2,5X,F4.0,6X,F3.0,7X,F4.0)
C ******************** INITIALIZATION OF CONSTANTS ***************
         DOUBLE PRECISION DIRECT, SDIP
         PI=3.1459265
         IF (CLINA .LT. .0087266) GO TO 5925
         HDIP=PI/2.0-CLINA
         AZI=AZI-DECLIN
         IF (AZI .LT. 0.0000) AZI=AZI+2.0*PI
         IF (AZI .GT. 2.0*PI) AZI=AZI-2.0*PI
         DELDEP=DEPMB-DEPMT
         IF (DELDEP .EQ. 0.0000) DDIPAZ=AZI-PI
         IF (DDIPAZ .LT. 0.0000) DDIPAZ=DDIPAZ+2.0*PI
         B=SQRT((TAN(HDIP))*(TAN(HDIP))+(COS(AZI))*(COS(AZI)))
         IF (IJUDGE .EQ. 1) GO TO 5300
C ********** CORRECTION FOR VERTICAL COMPONENT - TO LABLE 5300 ******
         AMP=COS(VERTC)*COS(AZI)*COS(HDIP)+SIN(VERTC)*SIN(HDIP)
         IF (AMP .EQ. 0.00000) GO TO 5000
         IF (AMP .GT. 1.0000000000) AMP=1.00000000
         QMAG=SQRT(1.000000000-(AMP*AMP))
         IF (QMAG .EQ. 0.00000) GO TO 5100
 4700    TEMP=((((COS(VERTC)-AMP*COS(AZI)*COS(HDIP))
      $  *TAN(HDIP))-((SIN(VERTC)-AMP*SIN(HDIP))
      $  *COS(AZI)))/(B*QMAG))
         IF (TEMP .GT. 1.000000000) GO TO 4800
         IF (TEMP .LT. -1.0000000000) GO TO 4900
         THETA=ACOS(TEMP)
         GO TO 5200
 4800    THETA=0.0000000000
         GO TO 5200
 4900    THETA=PI
         GO TO 5200
 5000    QMAG=1.000000000
         GO TO 4700
 5100    TYPE 4600
         GO TO 6100
 5200    IF (AZI .GE. PI) TDIPAZ=DDIPAZ+THETA
         IF (AZI .LT. PI) TDIPAZ=DDIPAZ-THETA
         DDIPAZ=TDIPAZ
         IF (DDIPAZ .LT. 0.0000) DDIPAZ=DDIPAZ+2.0*PI
         IF (DDIPAZ .GT. 2.0*PI) DDIPAZ=DDIPAZ-2.0*PI
 5300    FSTRIK=DDIPAZ-PI/2.0
```

Table 3.--*Fortran program listing--Single-fracture version*--Continued

```
C ********************** CHECK OF FRACTURE STRIKE ****************
       IF (FSTRIK .LT. 0.0000) FSTRIK=PI*2.0+FSTRIK
       IF (FSTRIK .GT. PI*2.0) GO TO 5400
       IF (FSTRIK .LT. 0.0000) GO TO 5400
       GO TO 5500
 5400  TYPE 4300
       GO TO 6100
C * GEOMETRICAL ROTATION OF FRACTURE PLANE TO SURFACE COORDINATE SYSTEM
 5500  IF (DELDEP .LT. 0.0000) GO TO 5600
       GO TO 5700
 5600  TYPE 4300
       GO TO 6100
 5700  FDIP=ATAN2(DELDEP,DIAMET)
       ALFAF=((-SIN(FDIP)/B)*(SIN(FSTRIK)*TAN(HDIP)+
     $ COS(FSTRIK)*SIN(AZI)*COS(AZI)*COS(HDIP)))-
     $ (COS(FDIP)*COS(AZI)*COS(HDIP))
       BETAF=(B*SIN(FDIP)*COS(FSTRIK)*COS(HDIP))-
     $ (COS(FDIP)*SIN(AZI)*COS(HDIP))
       GAMMAF=((SIN(FDIP)/B)*(SIN(FSTRIK)*COS(AZI)-
     $ COS(FSTRIK)*SIN(AZI)*SIN(HDIP)))-(COS(FDIP)*SIN(HDIP))
       IF (GAMMAF .LT. 0.0000) GO TO 5800
       GAMMAF=-GAMMAF
       BETAF=-BETAF
       ALFAF=-ALFAF
 5800  DIP=180.-((ACOS(GAMMAF))*180./PI)
       IF (DIP .LT. .5) GO TO 6000
       DIPAZ=(ATAN2(BETAF,ALFAF))*180./PI
       DIPAZ=DIPAZ+(DECLIN*180./PI)
C ************* DETERMINATION OF DOWN DIP DIRECTION **********
 5900  IF (DIPAZ .LT. 0.00) DIPAZ=360.+DIPAZ
       IF (DIPAZ .GT. 360.00) DIPAZ=DIPAZ-360.
       IF (DIPAZ .GT. 360.00 .OR. DIPAZ .LT. 0.00) GO TO 5400
 5915  STRIKE=DIPAZ-90.00
       IF (STRIKE .LT. 0.00) STRIKE=STRIKE+360.
       IF (STRIKE .GT. 180.00) STRIKE=STRIKE-180.
       IF (DIP .GT. 89.5) GO TO 5950
C ******************* OUTPUT OF RESULTS **********************
       TYPE 4620, DEPMT, DEPMB, STRIKE, DIP, DIPAZ
       GO TO 6100
 5925  DIP=(ATAN2(DELDEP,DIAMET))*180./PI
       DIPAZ=DDIPAZ*180./PI
       GO TO 5915
 5950  TYPE 4550, DEPMT, DEPMB, STRIKE
       GO TO 6100
 6000  TYPE 4500, DEPMT, DEPMB
 6100  RETURN
       END
```

Table 4.--*Fortran program listing--Single-well version*

```
C THIS PROGRAM CALCULATES THE TRUE ORIENTATION OF PLANAR STRUCTURES
C INTERSECTED BY THE BOREHOLE AS VIEWED WITH THE ACOUSTIC TELEVIEWER.
C
C ************************ DIRECTIONS ********************************
C   DATA INPUT FILE:
C    CREATE A FILE CALLED INDAT.DAT; THE FIRST LINE SHOULD CONTAIN
C    THE TRUE DEPTH, TRUE DEPARTURE AND TRUE LATITUDE (IN THAT ORDER)
C    FOR THE FIRST SURVEY STATION.  THESE VALUES WILL BE READ WITH
C    FORMAT STATEMENT 2000.  THE NEXT LINE WILL BE READ WITH FORMAT
C    STATEMENT 2100.  THIS LINE CONTAINS THE MEASURED DEPTH, AZIMUTH
C    AND INCLINATION OF THE FIRST STATION.  THE PROGRAM AS WRITTEN
C    WILL ACCEPT UP TO 100 STAIONS IF A LARGER NUMBER
C    IS REQUIRED INCREASE THE DIMENSIONED SIZE OF ALL THE ARRAYS.
C    TO TERMINATE STATION DATA INSERT -1.0 FOR THE FIRST VALUE OF
C    THE LAST LINE.  AFTER THE STATION DATA COMES THE FRACTURE DATA;
C    IT IS READ WITH STATEMENT 2200. AS MANY LINES AS DESIRED MAY BE
C    ENTERED.  EACH LINE MUST HAVE THE FIRST TWO VALUES: MEASURED DEPTH
C    TO FRACTURE TOP AND BOTTOM; BUT IF THESE VALUES ARE THE SAME,
C    ENTRY OF THE THIRD VALUE (DOWN DIP AZIMUTH) MAY BE OMITTED.
C    THE FOURTH VALUE IS AN OPTIONAL DIAMETER TO BE USED FOR THE
C    IMMEDIATE FRACTURE AND ALL THAT FOLLOW UNTIL THE VALUE IS AGAIN
C    CHANGED BY ENTRY OF SOME OTHER NON-ZERO NUMBER IN THE FOURTH
C    SPOT.  THE DIAMETER SHOULD BE ENTERED IN THE SAME UNITS AS THE
C    DEPTH MEASUREMENTS.  FOR EXAMPLE IF THE HOLE IS 3 INCHES IN
C    DIAMETER BUT THE DEPTHS ARE IN FEET THEN THE DIAMETER SHOULD
C    BE CHANGED TO 0.25 FEET.  FRACTURE DATA IS TERMINATED IN THE SAME
C    MANNER AS THE STATION DATA, WITH A -1 ON THE LAST LINE.
C                NOTE:  FRACTURE DATA SHOULD BE ENTERED NUMERICALLY
C                       WITH INCREASING DEPTH FOR RUNNING EFFICIENCY;
C                       HOWEVER IT IS NOT A NECESSITY, ANY FRACTURE
C                       OUTSIDE OF THE RANGE OF THE STATION DATA WILL
C                       BE IGNORED.
C
C   DATA INPUT FROM TERMINAL:
C    1. HOLE SURVEY METHOD - THREE METHODS ARE AVAILABLE:
C                                     RADIUS OF CURVATURE (1)
C                                     MINIMUM CURVATURE (2) AND
C                                     TANGENTIAL (3)
C       FOR TANGENTIAL ENTER TWO SURVEY STATIONS ONE AT THE TOP DEPTH
C       AND ONE AT THE BOTTOM DEPTH OF THE HOLE.  BOTH WITH IDENTIAL
C       AZIMUTH AND INCLINATION.
C    2. THE HOLE NAME MAY BE ANY 32 CHARACTER ALPHANUMBERIC STRING.
C    3. MAGNETIC DECLINATION - ENTER THE DESIRED PARAMETER INCLUDING
C       THE DECIMAL POINT.
C    4. IF YOU WISH TO INCLUED THE EFFECTS OF THE VERTICAL COMPONENT
C       OF THE MAGNETIC FIELD ENTER 1 FOR YES OR 2 FOR NO.
C    5. MAGNETIC INCLINATION - ENTER THE DESIRED PARAMETER INCLUDING
C       THE DECIMAL POINT.  NOTE THIS QUESTION WILL NOT BE ASKED IF
C       THE RESPONCE TO QUESTION 4 IS NEGATIVE.
C    6. COUNT THE LINES PER PAGE THAT YOUR PRINTER IS SET AT OR GUESS
C       (THE QUICK METHOD) AND ENTER A TWO DIGIT INTERGER NUMBER.
C    7. HOLE DIAMETER - ENTER IN CONSISTANT UNITS AS EXPLAINED ABOVE.
C       MAY BE SET TO ANY INITIAL VALUE.
C
C   DATA OUTPUT:
C    THE RESULTS ARE WRITTEN TO THE FILE OUTDAT.DAT.
C
C
C **************** FORMAT STATEMENTS *********************************
  100   FORMAT (/,1X,' HOLE SURVEY METHOD?',/,5X,'ENTER 1 FOR RADIUS
     $ OF CURVATURE,',/,11X,'2 FOR MINIMUM CURVATURE OR ',/,11X,
     $ '3 FOR TANGENTIAL:  ',$)
  200   FORMAT (/,1X,' HOLE NAME? ',$)
```

```
 300   FORMAT (4A8)
 400   FORMAT (/,1X,' MAGNETIC DECLINATION?',/,5X,'DEGREES
   $   (NEGATIVE FOR WEST): ',$)
 425   FORMAT (5X,'MINUTES:  ',$)
 450   FORMAT (5X,'SECONDS:  ',$)
 500   FORMAT (/,1X,' MAGNETIC INCLINATION?',/,5X,'DEGREES:   '$)
 600   FORMAT (F)
 800   FORMAT (/,1X,' HOW MANY LINES PER PAGE (ENTER INTEGER)? ',$)
 900   FORMAT (I2)
1000   FORMAT (/,1X,' DO YOU WISH TO INCLUDE THETA?
   $   (ENTER 1 FOR YES OR 2 FOR NO) ',$)
1100   FORMAT (I1)
1251   FORMAT (2X,'HOLE NAME:  ',2X,4A8,2X,'"TANGENTIAL"',2X,
   $   'MAG. DEC. = ',2X,3(1X,F3.0),2X,'MAGNETIC EFFECT EXCLUDED',2X
   $   ,'PG ',I5)
1252   FORMAT (4X,'HOLE NAME:  ',2X,4A8,2X,'"TANGENTIAL"',2X,'MAG. ',
   $   'DEC. = ',2X,3(1X,F3.0),2X,'MAG. INC. = ',2X,3(1X,F3.0),3X,
   $   'PG ',I5)
1253   FORMAT(' HOLE NAME:  ',2X,4A8,2X,'"MINIMUM CURVATURE"',2X,'MA',
   $     'G. DEC. = ',2X,3(1X,F3.0),2X,'MAGNETIC EFFECT EXCLUDED',
   $   2X,'PG ',I5)
1254   FORMAT (' HOLE NAME:  ',1X,4A8,2X,'"MINIMUM CURVATURE"',2X,
   $   'MAG. DEC. = ',1X,3(1X,F3.0),2X,'MAG. INC. = ',1X,3(1X,F3.0),
   $   2X,'PG ',I5)
1255   FORMAT (2X,'HOLE NAME:  ',1X,4A8,1X,'"RADIUS OF CURVATURE"',
   $   2X,'MAG. DEC. = ',1X,3(1X,F3.0),1X,'MAGNETIC EFFECT EXCLUDED',
   $   2X,'PG ',I5)
1256   FORMAT (' HOLE NAME:  ',1X,4A8,1X,'"RADIUS OF CURVATURE"',1X,
   $   'MAG. DEC. = ',1X,3(1X,F3.0),2X,'MAG. INC. = ',1X,
   $   3(1X,F3.0),2X,'PG ',I5)
1300   FORMAT (1X,131('*'))
1400   FORMAT (1X)
1450   FORMAT ('1')
1500   FORMAT (1X,'*',42X,'*',42X,'*',14X,'*',28X,'*')
1600   FORMAT (1X,'*',42X,'*',42X,'*',43X,'*')
1700   FORMAT (1X,'*',8X,'MEASURED DEPTH TO FRACTURE',
   $   8X,'*',6X,'COORDINATES OF FRACTURE CENTER',6X,
   $   '*',7X,'TRUE ORIENTATION OF FRACTURE',8X,'*')
1800   FORMAT (1X,'*',42X,'*',5X,'TRUE',7X,'DEPARTURE',
   $   6X,'LATITUDE',3X,'*',4X,'STRIKE',4X,'*',5X,'DIP',
   $   8X,'DOWN DIP ',3X,'*')
1900   FORMAT (1X,'*',4X,'CENTER',9X,'TOP',10X,'BOTTOM',
   $   4X,'*',4X,'DEPTH',7X,'+ FOR EAST',3X,'+ FOR NORTH',
   $   2X,'*',2X,'IN DEGREES',2X,'*',2X,'IN DEGREES',4X,
   $   'DIRECTION',3X,'*')
2000   FORMAT (3F)
2100   FORMAT (7F)
2200   FORMAT (6F)
2300   FORMAT (/,1X,' HOLE DIAMETER? (ENTER 0. IF VARIABLE) ',$)
2310   FORMAT (/)
C ******************* DIMENSION STATEMENTS ***************************
       DIMENSION ASD(100), ASA(100), ASI(100)
       DIMENSION ASDEPT(100), ASPART(100), ASLAT(100)
C ***************** INITIALIZATION OF CONSTANTS ***********************
       DOUBLE PRECISION ADDR1, ADDR2, ADDR3, ADDR4
       INTEGER PAGE, ACOUNT
       PI=3.14159265
       ICOUNT=1
       I=-1
       ACOUNT=1
       PAGE=1
       ITEST=0
C ***************** TERMINAL DATA ENTRY *******************************
2350   TYPE 100
```

```
      ACCEPT 1100, MEANS
      TYPE 200
      ACCEPT 300, ADDR1, ADDR2, ADDR3, ADDR4
      TYPE 400
      ACCEPT 600, DECD
      TYPE 425
      ACCEPT 600, DECM
      TYPE 450
      ACCEPT 600, DECS
      DEC=(PI/180.)*(DECD+DECM/60.+DECS/3600.)
      TYPE 1000
      ACCEPT 1100, METHOD
      IF (METHOD .EQ. 2) RINC=0.0
      IF (METHOD .EQ. 2) GO TO 2375
      TYPE 500
      ACCEPT 600, RINCD
      TYPE 425
      ACCEPT 600,RINCM
      TYPE 450
      ACCEPT 600, RINCS
      RINC=(PI/180.)*(RINCD+RINCM/60.+RINCS/3600.)
 2375 TYPE 800
      ACCEPT 900, J
      TYPE 2300
      ACCEPT 600, DIA
      TYPE 2310
      J=J-14
      M=J
C ********** ENTRY OF STATION DATA AND OPENING OF OUTPUT FILE **********
C ****************** INDIRECT LOOP TO LABLE 1200 **********************
      OPEN (UNIT=1,NAME='INDAT.DAT',TYPE='OLD',ACCESS='SEQUENTIAL')
      READ (1,2000) SDEPT1, SPART1, SLAT1
      READ (1,2100) SD1,Z1,Z2,Z3,Z4,Z5,Z6
      SA1=(PI/180.)*(Z1+Z2/60.+Z3/3600.)
      SI1=(PI/180.)*(Z4+Z5/60.+Z6/3600.)
      ASD(1)=SD1
      ASA(1)=SA1
      ASI(1)=SI1
      ASDEPT(1)=SDEPT1
      ASPART(1)=SPART1
      ASLAT(1)=SLAT1
      OPEN (UNIT=2,TYPE='NEW',NAME='OUTDAT.DAT')
      WRITE (2,1400)
      WRITE (2,1400)
      IF (MEANS .EQ. 3 .AND. METHOD .EQ. 2) WRITE (2,1251)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 3 .AND. METHOD .EQ. 1) WRITE (2,1252)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
      IF (MEANS .EQ. 2 .AND. METHOD .EQ. 2) WRITE (2,1253)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 2 .AND. METHOD .EQ. 1) WRITE (2,1254)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
      IF (MEANS .EQ. 1 .AND. METHOD .EQ. 2) WRITE (2,1255)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 1 .AND. METHOD .EQ. 1) WRITE (2,1256)
     $ ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
      WRITE (2,1400)
      WRITE (2,1300)
      WRITE (2,1600)
      WRITE (2,1700)
      WRITE (2,1600)
      WRITE (2,1300)
```

```
      WRITE (2,1500)
      WRITE (2,1800)
      WRITE (2,1900)
      WRITE (2,1500)
      WRITE (2,1300)
      WRITE (2,1500)
 2400 READ (1,2100) SD2, Z7, Z8, Z9, Z10, Z11, Z12
      IF (SD2 .LT. 0.0000) GO TO 2800
      ACOUNT = ACOUNT +1
      SA2=(PI/180.)*(Z7+Z8/60.+Z9/3600.)
      SI2=(PI/180.)*(Z10+Z11/60.+Z12/3600.)
C ********* CALCULATION OF TRUE COORDINATES OF STATIONS ****************
      DELI=SI2-SI1
      DELA=SA2-SA1
      DELD=SD2-SD1
      IF (MEANS .EQ. 3) GO TO 2600
      IF (MEANS .EQ. 1) GOTO 2500
      IF (MEANS .NE. 2) STOP
      DOG=ACOS(COS(DELI)-SIN(SI1)*SIN(SI2)*(1.0000-COS(DELA)))
      DOG2=DOG/2.0
      RF=(2.0/DOG)*TAN(DOG2)
      CD=((SD2-SD1)*RF)/2.0
      SDEPT1=SDEPT1+CD*(COS(SI1)+COS(SI2))
      SPART1=SPART1+CD*(SIN(SI1)*SIN(SA1)+SIN(SI2)*SIN(SA2))
      SLAT1=SLAT1+CD*(SIN(SI1)*COS(SA1)+SIN(SI2)*COS(SA2))
      GOTO 2700
 2500 SDEPT1=SDEPT1+(DELD*(SIN(SI2)-SIN(SI1))/DELI)
      SLAT1=SLAT1+(DELD*(COS(SI1)-COS(SI2))*
     $ (SIN(SA2)-SIN(SA1)))/(DELI*DELA)
      SPART1=SPART1+(DELD*(COS(SI1)-COS(SI2))*
     $ (COS(SA1)-COS(SA2)))/(DELI*DELA)
      GO TO 2700
 2600 SDEPT1=SDEPT1+(DELD*COS(SI1))
      SPART1=SPART1+(DELD*SIN(SI1)*SIN(SA1))
      SLAT1=SLAT1+(DELD*SIN(SI1)*SIN(SA1))
 2700 ASD(ACOUNT)=SD2
      ASA(ACOUNT)=SA2
      ASI(ACOUNT)=SI2
      ASDEPT(ACOUNT)=SDEPT1
      ASPART(ACOUNT)=SPART1
      ASLAT(ACOUNT)=SLAT1
      SA1=SA2
      SI1=SI2
      SD1=SD2
      GO TO 2400
C ****************** ENTRY OF FRACTURE DATA *****************************
C ************** INDIRECT LOOP TO LABLE 3800 ****************************
 2800 READ (1,2200) RMDEPT, RMDEPB, DIP1, DIP2, DIP3, RDIA
      IF (RMDEPT .LT. 0.0000) GOTO 4200
      DIPDIR=(DIP1+DIP2/60. +DIP3/3600.)*PI/180.
      IF (RDIA .EQ. 0.0000) RDIA=DIA
 2900 RMDEP=(RMDEPT+RMDEPB)/2.0
      SD1=ASD(ICOUNT)
      SI1=ASI(ICOUNT)
      SA1=ASA(ICOUNT)
      SDEPT1=ASDEPT(ICOUNT)
      SPART1=ASPART(ICOUNT)
      SLAT1=ASLAT(ICOUNT)
      ICOUNT=ICOUNT+1
      SI2=ASI(ICOUNT)
      SA2=ASA(ICOUNT)
      SD2=ASD(ICOUNT)
      ICOUNT=ICOUNT-1
```

```
      IF (RMDEP .LE. SD1 .OR. RMDEP .GT. SD2) GOTO 3800
      DELD=SD2-SD1
C ******** CALCULATION OF FRACTURE COORDINATES AND ORIENTATION *********
      IF (MEANS .EQ. 3) GO TO 3100
      HAZI=(((RMDEP-SD1)/DELD)*(SA2-SA1))+SA1
      HINC=(((RMDEP-SD1)/DELD)*(SI2-SI1))+SI1
      DELI=HINC-SI1
      DELA=HAZI-SA1
      IF (RMDEP .EQ. SD1) GOTO 3200
      IF (RMDEP .EQ. SD2) GO TO 3250
      IF (MEANS .EQ. 1) GO TO 3000
      IF (MEANS .NE. 2) STOP
      FDOG=ACOS(COS(DELI)-SIN(SI1)*SIN(HINC)*(1.0000-COS(DELA)))
      IF (FDOG .EQ. 0.0000000000000) GO TO 3200
      FDOG2=FDOG/2.0
      FRF=(2.0/FDOG)*TAN(FDOG2)
      TDEPTH=SDEPT1+(((RMDEP-SD1)/2.0)*(COS(SI1)+COS(HINC)))*FRF
      TDEPAR=SPART1+(FRF*(RMDEP-SD1)/2.0)*
     $ (SIN(SI1)*SIN(SA1)+SIN(HINC)*SIN(HAZI))
      TLATIT=SLAT1+(FRF*(RMDEP-SD1)/2.0)*
     $ (SIN(SI1)*COS(SA1)+SIN(HINC)*COS(HAZI))
      GO TO 3300
 3000 TDEPAR=SPART1+((RMDEP-SD1)*(COS(SI1)-COS(HINC))*
     $ (COS(SA1)-COS(HAZI)))/(DELI*DELA)
      TLATIT=SLAT1+((RMDEP-SD1)*(COS(SI1)-COS(HINC))*
     $ (SIN(HAZI)-SIN(SA1)))/(DELI*DELA)
      TDEPTH=SDEPT1+((RMDEP-SD1)*(SIN(HINC)-SIN(SI1))/DELI)
      GO TO 3300
 3100 HAZI=SA1
      HINC=SI1
      TDEPTH=(RMDEP-SD1)*COS(SI1)
      TDEPAR=(RMDEP-SD1)*SIN(SI1)*SIN(SA1)
      TLATIT=(RMDEP-SD1)*SIN(SI1)*COS(SA1)
 3101   FORMAT (3F)
      GO TO 3300
 3200 TLATIT=SLAT1
      TDEPTH=SDEPT1
      TDEPAR=SPART1
      GO TO 3300
 3250 ICOUNT=ICOUNT+1
      TLATIT=ASLAT(ICOUNT)
      TDEPTH=ASDEPT(ICOUNT)
      TDEPAR=ASPART(ICOUNT)
      ICOUNT=ICOUNT+1
 3300 DIA=RDIA
C ********** INTERNAL LOOP TO REGULATE OUTPUT FORMAT ***************
      I=I+1
      IF (I .EQ. 5) GO TO 3400
      GO TO 3700
 3400 WRITE (2,1500)
      I=0
      M=M-5
      IF (M .LT. 7) GO TO 3500
      GO TO 3700
 3500 WRITE (2,1300)
      WRITE (2,1450)
      PAGE=PAGE+1
      WRITE (2,1400)
      WRITE (2,1400)
      IF (MEANS .EQ. 3 .AND. METHOD .EQ. 2) WRITE (2,1251)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 3 .AND. METHOD .EQ. 1) WRITE (2,1252)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
```

```
      IF (MEANS .EQ. 2 .AND. METHOD .EQ. 2) WRITE (2,1253)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 2 .AND. METHOD .EQ. 1) WRITE (2,1254)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
      IF (MEANS .EQ. 1 .AND. METHOD .EQ. 2) WRITE (2,1255)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,PAGE
      IF (MEANS .EQ. 1 .AND. METHOD .EQ. 1) WRITE (2,1256)
     $  ADDR1,ADDR2,ADDR3,ADDR4,DECD,DECM,DECS,RINCD,RINCM,RINCS,PAGE
      WRITE (2,1400)
      WRITE (2,1400)
      WRITE (2,1300)
      WRITE (2,1600)
      WRITE (2,1700)
      WRITE (2,1600)
      WRITE (2,1300)
      WRITE (2,1500)
      WRITE (2,1800)
      WRITE (2,1900)
      WRITE (2,1500)
      WRITE (2,1300)
      WRITE (2,1500)
      M=J
C **CALLING OF SUBROUTINE ROTATE TO CALCULATE NEW PLANAR ORIENTATION **
 3700 CALL ROTATE (HAZI, HINC, DEC, RINC, RMDEP, RMDEPT, RMDEPB,
     $ TDEPTH, TDEPAR, TLATIT, DIPDIR, DIA, METHOD)
      GO TO 2800
C ****** BRANCH LOOP FOR CONTROLLING FRACTURE DATA CALCULATIONS *****
 3800 ICOUNT=ICOUNT+1
      IF (ICOUNT .GE. ACOUNT ) GO TO 4000
 3900 IF (ITEST .EQ. 2) GO TO 4100
      GO TO 2900
 4000 ITEST=ITEST+1
      ICOUNT=1
      GO TO 3900
 4100 ITEST=0
      GO TO 2900
C **************************** CLOSING OF FILES ****************************
 4200 WRITE (2,1500)
      WRITE (2,1300)
      CLOSE (UNIT=2,DISP='SAVE')
      CLOSE (UNIT=1,DISP='SAVE')
      STOP
      END
C ************************************************************************
      SUBROUTINE ROTATE (AZI, CLINA, DECLIN, VERTC, DEPTHM,
     $  DEPMT, DEPMB, TCDEP, TCDPT, TCLAT, DDIPAZ, DIAMET, IJUDGE)
C *********************** FORMAT STATEMENTS *************************
 4300 FORMAT (1X, '*', 9X,'ERROR DETECTED IN INPUT',10X,
     $ '*',42X,'*',14X,'*',28X,'*')
 4400 FORMAT (1X,'*',2X,F8.2,6X,F8.2,6X,F8.2,4X,'*',
     $ 2X,F8.2,6X,F8.2,6X,F8.2,4X,'*',5X,F4.0,5X,'*',4X,
     $ F4.0,11X,F4.0,5X,'*')
 4500 FORMAT (1X,'*',2X,F8.2,6X,F8.2,6X,F8.2,4X,
     $ '*',2X,F8.2,6X,F8.2,6X,F8.2,4X,'*',4X,
     $ 'HORIZONTAL FRACTURE NO STRIKE OR DIP',3X,'*')
 4550 FORMAT (1X,'*',2X,F8.2,6X,F8.2,6X,F8.2,4X,
     $ '*',2X,F8.2,6X,F8.2,6X,F8.2,4X,'*',5X,F4.0,5X,
     $ '*',6X,'VERTICAL FRACTURE',5X,'*')
 4600 FORMAT (1X,'*',2X,F8.2,6X,F8.2,6X,F8.2,4X,'*',2X,F8.2
     $ ,6X,F8.2,6X,F8.2,4X,'*',2X,' QMAG=0.0',3X,'*',5X,
     $ 'YOUR VERY FUNNY!!', 6X,'*')
C ****************** INITIALIZATION OF CONSTANTS ***************
      DOUBLE PRECISION DIRECT, SDIP
```

```
      PI=3.1459265
      IF (CLINA .LT. .0087266) GO TO 5925
      HDIP=PI/2.0-CLINA
      AZI=AZI-DECLIN
      IF (AZI .LT. 0.0000) AZI=AZI+2.0*PI
      IF (AZI .GT. 2.0*PI) AZI=AZI-2.0*PI
      DELDEP=DEPMB-DEPMT
      IF (DELDEP .EQ. 0.0000) DDIPAZ=AZI-PI
      IF (DDIPAZ .LT. 0.0000) DDIPAZ=DDIPAZ+2.0*PI
      B=SQRT((TAN(HDIP))*(TAN(HDIP))+(COS(AZI))*(COS(AZI)))
      IF (IJUDGE .EQ. 2) GO TO 5300
C ********** CORRECTION FOR VERTICAL COMPONENT - TO LABLE 5300 ******
      AMP=COS(VERTC)*COS(AZI)*COS(HDIP)+SIN(VERTC)*SIN(HDIP)
      IF (AMP .EQ. 0.00000) GO TO 5000
      IF (AMP .GT. 1.0000000000) AMP=1.00000000
      QMAG=SQRT(1.000000000-(AMP*AMP))
      IF (QMAG .EQ. 0.00000) GO TO 5100
 4700 TEMP=((((COS(VERTC)-AMP*COS(AZI)*COS(HDIP))
     $ *TAN(HDIP))-((SIN(VERTC)-AMP*SIN(HDIP))
     $ *COS(AZI)))/(B*QMAG))
      IF (TEMP .GT. 1.000000000) GO TO 4800
      IF (TEMP .LT. -1.0000000000) GO TO 4900
      THETA=ACOS(TEMP)
      GO TO 5200
 4800 THETA=0.0000000000
      GO TO 5200
 4900 THETA=PI
      GO TO 5200
 5000 QMAG=1.000000000
      GO TO 4700
 5100 WRITE (2,4600) DEPTHM,DEPMT,DEPMB,TCDEP,TCDPT,TCLAT
      GO TO 6100
 5200 IF (AZI .GE. PI) TDIPAZ=DDIPAZ+THETA
      IF (AZI .LT. PI) TDIPAZ=DDIPAZ-THETA
      DDIPAZ=TDIPAZ
      IF (DDIPAZ .LT. 0.0000) DDIPAZ=DDIPAZ+2.0*PI
      IF (DDIPAZ .GT. 2.0*PI) DDIPAZ=DDIPAZ-2.0*PI
 5300 FSTRIK=DDIPAZ-PI/2.0
C ********************* CHECK OF FRACTURE STRIKE ****************
      IF (FSTRIK .LT. 0.0000) FSTRIK=PI*2.0+FSTRIK
      IF (FSTRIK .GT. PI*2.0) GO TO 5400
      IF (FSTRIK .LT. 0.0000) GO TO 5400
      GO TO 5500
 5400 WRITE (2,4300)
      GO TO 6100
C * GEOMETRICAL ROTATION OF FRACTURE PLANE TO SURFACE COORDINATE SYSTEM
 5500 IF (DELDEP .LT. 0.0000) GO TO 5600
      GO TO 5700
 5600 WRITE (2,4300)
      GO TO 6100
 5700 FDIP=ATAN2(DELDEP,DIAMET)
      ALFAF=((-SIN(FDIP)/B)*(SIN(FSTRIK)*TAN(HDIP)+
     $ COS(FSTRIK)*SIN(AZI)*COS(AZI)*COS(HDIP)))-
     $ (COS(FDIP)*COS(AZI)*COS(HDIP))
      BETAF=(B*SIN(FDIP)*COS(FSTRIK)*COS(HDIP))-
     $ (COS(FDIP)*SIN(AZI)*COS(HDIP))
      GAMMAF=((SIN(FDIP)/B)*(SIN(FSTRIK)*COS(AZI)-
     $ COS(FSTRIK)*SIN(AZI)*SIN(HDIP)))-(COS(FDIP)*SIN(HDIP))
      IF (GAMMAF .LT. 0.0000) GO TO 5800
      GAMMAF=-GAMMAF
      BETAF=-BETAF
      ALFAF=-ALFAF
 5800 DIP=180.-((ACOS(GAMMAF))*180./PI)
```

```
      IF (DIP .LT. .5) GO TO 6000
      DIPAZ=(ATAN2(BETAF,ALFAF))*180./PI
      DIPAZ=DIPAZ+(DECLIN*180./PI)
C ************** DETERMINATION OF DOWN DIP DIRECTION ***********
 5900 IF (DIPAZ .LT. 0.00) DIPAZ=360.+DIPAZ
      IF (DIPAZ .GT. 360.00) DIPAZ=DIPAZ-360.
      IF (DIPAZ .GT. 360.00 .OR. DIPAZ .LT. 0.00) GO TO 5400
 5915 STRIKE=DIPAZ-90.00
      IF (STRIKE .LT. 0.00) STRIKE=STRIKE+360.
      IF (STRIKE .GT. 180.00) STRIKE=STRIKE-180.
      IF (DIP .GT. 89.5) GO TO 5950
C ******************** OUTPUT OF RESULTS ***********************
      WRITE (2,4400) DEPTHM, DEPMT, DEPMB, TCDEP, TCDPT,
     $ TCLAT, STRIKE, DIP, DIPAZ
      GO TO 6100
 5925 DIP=(ATAN2(DELDEP,DIAMET))*180./PI
      DIPAZ=DDIPAZ*180./PI
      GO TO 5915
 5950 WRITE (2,4550) DEPTHM, DEPMT, DEPMB, TCDEP,
     $ TCDPT, TCLAT, STRIKE
      GO TO 6100
 6000 WRITE (2,4500) DEPTHM, DEPMT, DEPMB,TCDEP,
     $ TCDPT, TCLAT
 6100 RETURN
      END
```

Table 5.--*Fortran variables*

1. ACOUNT - integer variable representing the station number.
2. ADDR - 10 alphanumeric character variable for the hole name.
3. ALFAF - a directional cosine of the fracture plane normal.
4. AMP - amplitude of the vector Q.
5. ASA - array variable storing station azimuths.
6. ASD - array variable storing station measured depths.
7. ASDEPT - array variable storing station true depths.
8. ASI - array variable storing station inclinations.
9. ASLAT - array variable storing station latitude.
10. ASPART - array variable storing station departure.
11. AZI - hole azimuth.
12. B - computational factor.
13. BETAF - a directional cosine of the fracture plane normal.
14. CD - calculation factor.
15. CLINA - hole inclination at center of fracture.
16. DDIPAZ - apparent down-dip azimuth of the fracture.
17. DEC - magnetic declination in radians.
18. DECD - degree portion of magnetic declination.
19. DECLIN - magnetic declination in radians.
20. DECM - minutes portion of the magnetic declination.
21. DECS - seconds portion of the magnetic declination.
22. DELA - delta azimuth = HAZI-SA1 or = SA2-SA1.
23. DELD - delta depth = SD2-SD1 or RMDEP-SD1.
24. DELDEP - the difference in measured depth between fracture top and bottom.
25. DELI - delta inclination = SI2-SI1.
26. DEPMB - measured depth to fracture bottom.
27. DEPMT - measured depth to fracture top.
28. DEPTHM - measured depth to fracture center.
29. DIA - diameter used for input into subroutine rotate = RDIA.
30. DIAMET - diameter at fracture center.
31. DIP - true dip azimuth of fracture.
32. DIP1 - degree portion of the down-dip azimuth.
33. DIP2 - minutes portion of the down-dip azimuth.
34. DIP3 - seconds portion of the down-dip azimuth.
35. DIPAZ - true down-dip azimuth of fracture.
36. DIPDIR - apparent down-dip azimuth of fracture - converted to radians.
37. DIRECT - alphanumeric variable for dip direction.
38. DOG - dogleg angle between stations.
39. DOG2 - = DOG/2.0.
40. FDIP - apparent fracture dip.
41. FDOG - fracture dogleg angle from station 1 to fracture.
42. FDOG2 - = FDOG/2.0.
43. FRF - ratio factor to fracture.
44. FSTRIK - fracture strike.
45. GAMMAF - a directional cosine of the fracture plane normal.
46. HAZI - hole azimuth in radians at point of interest.
47. HDIP - hole dip.
48. HINC - hole inclination in radians at point of interest.
49. I - integer used for controlling page output.
50. ICOUNT - integer variable for representing station number.

Table 5.--*Fortran variables*

51. IJUDGE - alphanumeric character representing the inclusion or exclusion of the vertical component.
52. INDEX - integer to control loop.
53. ITEST - integer for station cheek.
54. J - integer number of lines per page.
55. M - integer used for controlling page output.
56. MEANS - alphanumeric letter representing the hole survey method to be used.
57. METHOD - alphanumeric letter representing the inclusion and exclusion of theta.
58. PAGE - integer variable for page number of output.
59. PI - constant equal to 3.14159265.
60. QMAG - the magnitude of the vector R.
61. RDIA - hole diameter at fracture center.
62. RF - ratio factor between stations.
63. RINC - magnetic inclination in radians.
64. RINCD - degree portion of the magnetic inclination.
65. RINCM - minutes portion of the magnetic inclination.
66. RINCS - seconds portion of the magnetic inclination.
67. RMDEP - measured depth to fracture center.
68. RMDEPB - measured depth to fracture bottom.
69. RMDEPT - measured depth to fracture top.
70. SA1 - hole azimuth at station 1 (in radians).
71. SA2 - hole azimuth at station 2 (in radians).
72. SDEPTI - true depth to station 1.
73. SDIP - alphanumeric variable for dip direction.
74. SD1 - measured depth to station 1.
75. SD2 - measured depth to station 2.
76. SI1 - hole inclination at station 1 (in radians).
77. SI2 - hole inclination at station 2 (in radians).
78. SLATI - true latitude to station 1.
79. SPARTI - true departure to station 1.
80. STRIKE - true strike of the fracture.
81. TCDEP - true coordinates of fracture depth = TDEPTH.
82. TCDPT - true coordinates of fracture departure = TDEPAR.
83. TCLAT - true coordinates of fracture latitude = TLATIT.
84. TDEPTH - true vertical depth to fracture center.
85. TDEPAR - true departure depth to fracture center.
86. TDIPAZ - temporary variable.
87. TEMP - temporary calculation factor.
88. THETA - θ
89. TLATIT - true latitude to fracture center.
90. VERTC - magnetic inclination.
91. Z1 - degree portion of the azimuth at station 1.
92. Z2 - minutes portion of the azimuth at station 1.
93. Z3 - seconds portion of the azimuth at station 1.
94. Z4 - degrees portion of the inclination at station 1.
95. Z5 - minutes portion of the inclination at station 1.
96. Z6 - seconds portion of the inclination at station 1.
97. Z7 - degree portion of the azimuth at station 2.
98. Z8 - minutes portion of the azimuth at station 2.
99. Z9 - seconds portion of the azimuth at station 2.
100. Z10 - degrees portion of the inclination at station 2.
101. Z11 - minutes portion of the inclination at station 2.
102. Z12 - seconds portion of the inclination at station 2.

Table 6.--*Theta values*

MAGNETIC INCLINATION: 67°

HOLE AZIMUTH (degrees)	Hole inclination, in degrees																
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
10.	-3.	-7.	-17.	-46.	-112.	-143.	-154.	-159.	-163.	-165.	-167.	-169.	-170.	-171.	-172.	-174.	-175.
20.	-5.	-14.	-30.	-58.	-95.	-119.	-133.	-141.	-147.	-151.	-154.	-157.	-160.	-163.	-165.	-167.	-170.
30.	-7.	-19.	-36.	-61.	-85.	-104.	-117.	-126.	-132.	-138.	-142.	-147.	-151.	-154.	-158.	-161.	-165.
40.	-9.	-22.	-40.	-59.	-78.	-93.	-104.	-113.	-120.	-126.	-131.	-136.	-141.	-146.	-151.	-155.	-160.
50.	-11.	-24.	-40.	-57.	-71.	-83.	-93.	-101.	-108.	-114.	-120.	-125.	-131.	-137.	-143.	-149.	-156.
60.	-11.	-25.	-39.	-53.	-65.	-74.	-83.	-90.	-96.	-102.	-107.	-113.	-120.	-126.	-134.	-142.	-151.
70.	-12.	-25.	-37.	-48.	-58.	-66.	-73.	-79.	-84.	-89.	-94.	-99.	-105.	-113.	-121.	-132.	-144.
80.	-12.	-24.	-35.	-44.	-51.	-58.	-63.	-67.	-71.	-75.	-79.	-83.	-87.	-93.	-100.	-112.	-131.
90.	-12.	-22.	-31.	-39.	-45.	-50.	-53.	-57.	-59.	-61.	-63.	-64.	-65.	-66.	-66.	-67.	-67.
100.	-11.	-20.	-28.	-34.	-38.	-42.	-44.	-46.	-47.	-47.	-47.	-46.	-43.	-39.	-33.	-22.	-4.
110.	-10.	-18.	-24.	-29.	-32.	-35.	-36.	-37.	-37.	-36.	-34.	-31.	-27.	-21.	-14.	-4.	-8.
120.	-9.	-16.	-21.	-24.	-27.	-28.	-29.	-28.	-28.	-26.	-23.	-20.	-16.	-11.	-4.	-3.	-11.
130.	-8.	-13.	-17.	-20.	-21.	-22.	-22.	-22.	-20.	-18.	-16.	-13.	-9.	-5.	0.	-6.	-12.
140.	-6.	-11.	-14.	-15.	-16.	-17.	-17.	-16.	-14.	-13.	11.	-8.	-5.	-1.	-2.	-6.	-11.
150.	-5.	-8.	-10.	-11.	-12.	-12.	-12.	-11.	-10.	-8.	-7.	-5.	-2.	0.	-3.	-6.	-9.
160.	-3.	-5.	-7.	-7.	-8.	-8.	-7.	-7.	-6.	-5.	-4.	-3.	-1.	-1.	-2.	-4.	-6.
170.	-2.	-3.	-3.	-4.	-4.	-4.	-4.	-3.	-3.	-2.	-2.	-1.	0.	0.	-1.	-2.	-3.
180.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
190.	2.	3.	3.	4.	4.	4.	4.	3.	3.	2.	2.	1.	0.	0.	1.	2.	3.
200.	3.	5.	7.	7.	8.	8.	7.	7.	6.	5.	4.	3.	1.	1.	2.	4.	6.
210.	5.	8.	10.	11.	12.	12.	12.	11.	10.	8.	7.	5.	2.	0.	3.	6.	9.
220.	6.	11.	14.	15.	16.	17.	17.	16.	14.	13.	11.	8.	5.	1.	2.	6.	11.
230.	8.	13.	17.	20.	21.	22.	22.	22.	20.	18.	16.	13.	9.	5.	0.	6.	12.
240.	9.	16.	21.	24.	27.	28.	29.	28.	28.	26.	23.	20.	16.	11.	4.	3.	11.
250.	10.	18.	24.	29.	32.	35.	36.	37.	37.	36.	34.	31.	27.	21.	14.	4.	8.
260.	11.	20.	28.	34.	38.	42.	44.	46.	47.	47.	47.	46.	43.	39.	33.	22.	4.
270.	12.	22.	31.	39.	45.	50.	53.	57.	59.	61.	63.	64.	65.	66.	66.	67.	67.
280.	12.	24.	35.	44.	51.	58.	63.	67.	71.	75.	79.	83.	87.	93.	100.	112.	131.
290.	12.	25.	37.	48.	58.	66.	73.	79.	84.	89.	94.	99.	105.	113.	121.	132.	144.
300.	11.	25.	39.	53.	65.	74.	83.	90.	96.	102.	107.	113.	120.	126.	134.	142.	151.
310.	11.	24.	40.	57.	71.	83.	93.	101.	108.	114.	120.	125.	131.	137.	143.	149.	156.
320.	9.	22.	40.	59.	78.	93.	104.	113.	120.	126.	131.	136.	141.	146.	151.	155.	160.
330.	7.	19.	36.	61.	85.	104.	117.	126.	132.	138.	142.	147.	151.	154.	158.	161.	165.
340.	5.	14.	30.	58.	95.	119.	133.	141.	147.	151.	154.	157.	160.	163.	165.	167.	170.
350.	3.	7.	17.	46.	112.	143.	154.	159.	163.	165.	167.	169.	170.	171.	172.	174.	175.
360.	0.	0.	0.	0.	180.	180.	180.	180.	180.	180.	180.	180.	180.	180.	180.	180.	180.

Table 7.--*Theta program listing*

```
LBL "THETA"
"VERTICAL COMP?"
PROMPT
STO 01
"HOLE INC?"
PROMPT
CHS
90.000000
+
STO 02
"HOLE AZI?"
PROMPT
STO 03
COS
RCL 02
COS
*
RCL 01
COS
*
RCL 01
SIN
RCL 02
SIN
*
+
STO 04
1.0000000
X<=Y?
STO 04
CHS
X>Y?
STO 04
RCL 04
X↑2
CHS
1.000000000
+
SQRT
STO 05
X=0?
GTO 01
RCL 01
COS
RCL 02
COS
RCL 03
COS
*
RCL 04
*
-
RCL 02
TAN
*
RCL 04
RCL 02
SIN
*
CHS
RCL 01
SIN
+
RCL 03
COS
*
-
RCL 02
TAN
X↑2
RCL 03
COS
X↑2
+
SQRT
/
RCL 05
/
ACOS
LBL 01
.END.
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