SCIENTIFIC NOTEBOOK 685E

SYNTHESIS OF SUBSURFACE FRACTURE DATA COLLECTED AT YUCCA MOUNTAIN, NEVADA

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OBJECTIVES

The objectives are to compile and synthesize all available subsurface fracture data collected at Yucca Mountain, and to analyze the data for use in areas such as performance confirmation, drift degradation, and flow in the unsaturated zone. The data sets include detailed line surveys (DLS) and full-periphery geologic maps (FPGM) collected by the Department of Energy (DOE) and it's contractors (e.g., U.S. Geological Survey, U.S. Bureau of Reclamation) in the Exploratory Studies Facility (ESF) and the Enhanced Characterization of the Repository Block (ECRB) Cross-Drift. This analysis will provide the Nuclear Regulatory Commission (NRC) staff and its contractors with a complete, up-to-date summary of fracture characteristics at Yucca Mountain that can be used during license review to evaluate features, events and processes related to repository construction and operation.

SPECIFIC TASKS

Tasks to be completed during this work include:

1. Compiling DLS fracture data – initial analyses by K.J. Smart are documented in Scientific Notebook 606E (p. 29-46), and will be continued in this notebook.
2. Extraction of fracture data from FPGM – P. Landis and D. Waiting
3. Generation of synthetic fracture populations with FracMan – D. Wyrick

December 20, 2004 PSL

EXTRACTION OF DATA FROM FULL-PERIPHERY GEOLOGIC MAPS (FPGM)

The following entries describe the process by which data was extracted from the FPGMs for the ECRB (DTN: GS990408314224.003 - DTN: GS990408314224.006). All entries in the following section were made by Paul Landis unless otherwise noted in the text. All files in bold will be provided in the electronic notebook. Furthermore, since this process only details one 100m section of the ECRB, all files from the ECRB will be provided.

ENTRY 1: TURBOCAD DATA EXTRACTION

The ECRB files are provided in two formats: .dxf and .dwg. A four digit number describing the station (ie. Cbd2200.dxf) precedes the file extension. Only .dxf files were used in the ECRB data extraction process. To begin the data extraction process, open TurboCAD v10.2 and open the target ECRB file (the file cbd2200.dxf will be used). The DOE grouped the full-periphery geologic maps into three panels. To ungroup them, select the panel and explode the panel (ctrl-alt-E). Under the 'Options' menu, select 'Layers' and delete the following layers in the pop-up box:

- Tunnel
- Title
- Spline
- Store
- St-Nets
- TOP_PNL
- BOT_PNL
- GRID1
- 10GRID
- TXT3
- RQD
- 61-100
- S61-100
- DIP
- BLANK
- AME-FRZ
- CAT
- TBM
- TXT2-5
- TXT2
- 23-2200C
- 23-2200C1 - C7
- CLUS1CNT
- HATCH
- 23-2200S
- 23-2200S2 -S7
- All files with the XSEC2200$1$ prefix
- XNDX2200$0$STEEL
- XNDX2200$0$STLTXT
- XNDX2200$0$RKBLT
- XNDX2200$0$END
- XNDX2200$0$MESH
- XNDX2200$0$CENTER

- XNDX2200$0$SPRINGLINE
- XNDX2230$0$STEEL
- XNDX2230$0$STLTXT
- XNDX2230$0$RKBLT
- XNDX2230$0$END
- XNDX2230$0$MESH
- XNDX2230$0$CENTER
- XNDX2230$0$SPRINGLINE
- XNDX2260$0$STEEL
- XNDX2260$0$STLTXT
- XNDX2260$0$RKBLT
- XNDX2260$0$END
- XNDX2260$0$MESH
- XNDX2260$0$CENTER
- XNDX2260$0$SPRINGLINE

Save the altered .dxf as **cbd2200.fpg.dxf** and close TurboCAD.

ENTRY 2: EXTRACTING STRIKE AND DIP DATA

Open the application ArcMap 9, create a new map and add **cbd2200.fpg.dxf** as new data. Under the 'Selection' menu, choose 'Select by Attributes'. The dip data is embedded in the **cbd2200.fpg.dxf** point layer and needs to be extracted. Enter the following formula in the query calculator:

"DIP" > 0

This formula creates a new selection from the point shapefile. Click 'Apply' and then 'Close'.

Right-click on the **cbd2200.fpg.dxf** point shapefile and select the 'Data' option. Under 'Data' select 'Export Data'. In the popup menu specify that you want to export the selected features and then specify the path name where you want to save the file. I chose to name the file **2200dip.shp**. Click 'Ok' and add the data as a new layer.

To extract the strike data, choose the 'Selection' menu and 'Select by Attributes' again. This time, specify the **cbd2200.fpg.dxf** polyline shapefile as the target. In the query calculator input the following formula:

"Layer" = 'XNDX2200$0$FRAC' OR "Layer" = 'XNDX2230$0$FRAC' OR "Layer" = 'XNDX2260$0$FRAC' OR "Layer" = 'XNDX2200$0$VPP' OR "Layer" = 'XNDX2230$0$VPP' OR "Layer" = 'XNDX2260$0$VPP' OR "Layer" = 'XNDX2200$0$FAULT' OR "Layer" = 'XNDX2230$0$FAULT' OR "Layer" = 'XNDX2260$0$FAULT' OR "Layer" = 'XNDX2200$0$SHEAR' OR "Layer" = 'XNDX2230$0$SHEAR' OR "Layer" = 'XNDX2260$0$SHEAR'

This formula lists all the possible layers that were mapped as having measurable offset (faults, fractures, shear, vapor phase partings). Many full-periphery geologic maps do not contain all of the above layers and the formula needs to be adjusted accordingly. The number after XNDX is the station number. Click 'Apply' and then 'Close'.

Right-click on **cbd2200.fpg.dxf** polyline and choose the 'Data' option. Under the 'Data' option, choose 'Export Data' and specify that you want to export selected features and specify the path where you want to save the file. I chose to name the file **2200all.shp**. Click 'OK' and add the

data as a new layer.

In the Editor toolbar, select 'Start Edition'. The target should be **2200all.shp** and the task is 'Modify Feature'. Under the 'Selection' menu choose 'Select by Attributes' and specify that the layer to select from is **2200all.shp**. In the query calculator input the following formula:

"Text" = 'XNDX2200$0$FEND' OR "Text" = 'XNDX2230$0$FEND' OR
"Text" = 'XNDX2260$0$FEND'

Click 'Apply' and 'Close'. This formula selects the polylines that were constructed in CAD by the DOE as the fracture endpoints. Using the Edit select tool, right-click on a selected feature and choose 'Delete'. In the Editor menu, 'Save Edits' and then 'Stop Editing'.

ENTRY 3: JOINING STRIKE AND DIP DATA

Right-click on the **2200frac.shp** file, choose 'Joins and Relates' and then 'Join'. In the drop down menu select 'Join data from another layer based on spatial location'. A variety of options will pop up. Make sure that 'the layer to join this data or load spatial data from disk' is **2200dip.shp**. Rename the joined file as **2200all_data.shp**. Click 'OK'. The new shapefile should be added as a layer.

Under the 'Selection' menu, select 'Select by Attributes'. The target layer is **2200all_data.shp**. Enter the following formula in the query calculator:

"Distance" > 0.2

'Apply' and then 'Close'. This formula selects all the fracture traces that are more than 0.2m away from a dip measurement. In the editing toolbar, select 'Start Editing'. Right-click on **2200all_data.shp** and 'Open Attribute Table'. In the attribute table choose show: selected. Replace all the selected values in the Strike_1 column and the Dip_1 column with 0. In the editing toolbar, select 'Save Edits' and then 'Stop Editing'.

ENTRY 4: EXTRACTING COORDINATE DATA

Launch the application ArcView GIS 3.2a. Create a project with a new view and add the theme **2200all_data.shp**. Under the 'Theme' menu, select 'Start Editing'.

The next step is somewhat arbitrary. A number of the fractures contain drafting errors that greatly exaggerate the total trace length. For example, many fractures are digitized numerous times. In order to fix this problem, select the 'Vertex Edit' button in the main toolbar and then select a fracture that is digitized multiple times. To delete the multiple points, place the cursor near the extra points and press 'Delete' on the keyboard. Repeat until a single continuous fracture remains. In the 'Theme' menu, 'Save Edits' and then 'Stop Editing'.

In the 'File' menu under 'Extensions' select the 'Get Vertices' extension. This will add a 'XY' button in the main toolbar. Click the 'XY' button. Specify the theme as **2200all_data.shp** in the pop-up box and select 'Ok'. In the next popup box the name field for the theme is FID_1. A table displaying coordinate data for all fractures will load. Under the 'File' menu, select 'Export' and specify the format as dBASE. Name the file **2200frac_coor.dbf**. Click the 'XY' button again and this time specify the Strike_1 theme and export the table as **2200strike.dbf**. Once

more, click the 'XY' button and specity the Dip_1 theme and export the table as **2200dipxy.dbf**. Close ArcView GIS 3.2a.

ENTRY 5: EXTRACTING TRACE LENGTH

Open the application Microsoft Excel and open the file **2200frac_coor.dbf**. The format should be as follows: column A is FID1, column B is XCOORD, and column C is YCOORD. If not, rearrange the columns to match the format.

The next step involves a series of conditional formulas that will eventually result in a total trace length for each fracture. In column E input the formula:

=IF(A2=A3,SQRT((B2-B3)^2+(C2-C3)^2),0)

This formula calculates the distance between each segment. In column G, input the next formula:

=IF(A1=A2, G1+E2,E2)

This formula sums the segment lengths and provides the total trace length for each fracture. In column I, input the following formula:

=IF(G2=G3,G2,0)

This formula nulls all values that are not the total length of the fracture. Finally, in column K, copy column I and paste the values ('Paste Special' values). Save this file as a Microsoft Excel workbook and name it **2200frac_coor.xls**.

Create a new workbook and select columns A, B, C, and K in **2200frac_coor.xls**. Copy the columns and paste thm in the new workbook. Save the workbook as **2200length.xls**. Open the files **2200strike.dbf** and **2200dipxy.dbf**. Copy the respective strike and dip columns from the .dbf files and paste them into **2200length.xls** and save the workbook.

ENTRY 6. CALCULATING FAULT DENSITY

In the file **2200length.xls**, select all columns. Under the 'Data' menu, choose 'Filter' and then 'AutoFilter'. Tabs should appear in the column titles. Select the tab in the 'length' column and select 'Custom'. A pop-up window will appear and choose 'does not equal' and type 0 in the next column. Click 'OK'.

This filtering process filters out the null values (0) in the length column and only displays rows that have the total trace length value. In the 'Data' menu, select 'Sort' and then sort descending in the XCOORD column.

In a separate column, sum the total trace length for 10m intervals, using the =SUM() function. Next to the sum column, calculate the fault density by dividing the total trace length column by unit area (interval * circumference or 10*14.3). It is important to note, that is process only provides correct densities if the worksheet is filtered and sorted properly.

**Note: This process can be repeated for every 100m interval for the ECRB. The only

difference is the number attached to the file names and formulas. For example, files in the interval from 1000m-1100m would be named '1000all.shp'. For formulas used in ArcGIS, the first two numbers of the station need to be changed (ie. the formula would read: "Text" = 'XNDX1030$0$FEND' and so forth).

ENTRY 7: EXPORTING DATA FROM THE ESF

Exporting data from the ESF follows the same procedure as above except that none of the .dxf files provided for the ESF will open in TurboCAD v10.2. Therefore, the process should begin at the 'EXTRACTING STRIKE AND DIP DATA' section.

December 29, 2004 DYW

VERIFYING STOCHASTIC FRACTURE GENERATION STATISTICS VERSUS BOX REGION USING FRACMAN

A series of simulations were performed using FracMan (Dershowitz and Herda, 1992; Golder Associates Inc., 1998, 2002) to determine if the fracture sets generated within various region boxes were consistent. Refer to the Software Validation Testing for FracMan version 2.6 for simulations performed to assess the statistical calculations of the software. This testing was done to determine if the software accounted for region geometric shape when generating fracture sets. Specifically, given a set number of fractures in a given volume, does the shape of the box region affect the fractures statistics of P_{32} and fracture length?

TEST DESIGN

To determine what effect, if any, region shape had on fracture intensity values, four region boxes were created. These boxes have the same total volume, but comprised of a cube, a vertical tabular box, a rod shaped box, and a horizontal tabular box. The fracture set definitions (e.g., fracture orientation, size) remained constant for all for boxes. The number of fractures generated with a given size in a given volume was also constant for all tests. After fracture generation, three traceplane were created to sample fracture data. These traceplanes were placed orthogonal to each other and situated well within each box in order to avoid sampling outside the fracture generation region. The statistics from the traceplanes were then compared from the series of tests to determine if values were within the testing parameters described in the Software Validation Test.

Region box dimensions:

Box 1: 20 m x 20 m x 20 m = 8000m^3
Box 2: 10 m x 40 m x 20 m = 8000m^3
Box 3: 80 m x 10 m x 10 m = 8000m^3
Box 4: 32 m x 10 m x 25 m = 8000m^3

Fracture set definitions:

Generation region = standard, Box 1
Clipping region = standard, Box 1
Generation model = Enhanced Baecher
Fracture intensity = measure by number of fractures
Parameters = 100 fractures
Fracture orientation: Fisher distribution, trend = 10, plunge = 45, dispersion = 100
Orientation specified by = Pole
Fracture size = Constant, parameter = 2
Fracture shape = 6 sides
Transmissivity = Constant
Storativity = Constant
Aperture = Constant
Termination percentage = 0

Traceplane definitions:

A FracMan *.SAB file was created using the following parameters:

```
BEGIN COORDinate_system
    XAxis = East
END
```

```
BEGIN traceplane
    name = "Traceplane 1"
    origin = -5 0 0
    scan_trend = 90
    scan_plunge = 0
    scan_length = 10
    tran_trend = 90
    tran_plunge = 90
    tran_width = 10
END

BEGIN traceplane
    name = "Traceplane 2"
    origin = 0 -5 0
    scan_trend = 0
    scan_plunge = 0
    scan_length = 10
    tran_trend = 0
    tran_plunge = 90
    tran_width = 10
END

BEGIN traceplane
    name = "Traceplane 3"
    origin = -5 0 0
    scan_trend = 90
    scan_plunge = 0
    scan_length = 10
    tran_trend = 0
    tran_plunge = 0
    tran_width = 10
END
```

TEST IMPLEMENTATION

Two complete tests were run using the stochastic generation of fractures defined from the parameters above. Refer to the Software Validation Test or Golder Associates Inc. (1998, 2002) for complete instruction on generating synthetic fracture populations in FracMan. After generation of the fracture set, the traceplanes were imported using the File ->Import->SAB file. Select the *.sab ASCII file with the parameters described above. Select Analysis->Statistics. This generatee a series of fracture set statistics, including fracture density (P_{32}). For statistics on specific traceplanes, select Analysis->Exploration->Traceplane. Select a traceplane (e.g., Traceplane 1) and the Fracture Set Definition (there was only one fracture set for this test). This generated fracture statistics along the traceplane, including the number of intersecting fractures and total trace length. The statistical analysis was repeated for all three traceplanes. The information was then exported by right clicking inside the statistics window and selecting Save to File. This exports an ASCII file that can be read by Excel. The entire procedure was then repeated for the remaining box regions.

TEST RESULTS

The following table summarizes the testing for all box shapes. The variation noted in the traceplane analyses falls within acceptable ranges based on the Software Validation Test parameters. This should provide confidence that the geometric shape of a synthetic fracture population (i.e., the thickness of a horizon) will not produce anomalous fracture statistics. The orientation and size of the sampling traceplane should be such that it will capture a true sample of the fracture populations.

Test 1	Box 1 dimensions 20x20x20	Box 2 dimensions 10x40x20	Box 3 dimensions 80x10x10	Box 4 dimensions 32x10x25
Traceplane 1	Box 1	Box 2	Box 3	Box 4
# of fractures	3	3	2	7
Total trace length	4.4366	5.31131	2.62638	17.163
Avg trace length	1.478866667	1.770436667	1.31319	2.451857143
Traceplane 2	Box 1	Box 2	Box 3	Box 4
# of fractures	5	7	6	7
Total trace length	6.6462	12.9001	16.7712	15.2861
Avg trace length	1.32924	1.842871429	2.7952	2.183728571
Traceplane 3	Box 1	Box 2	Box 3	Box 4
# of fractures	4	4	3	3
Total trace length	5.72149	9.71143	8.77145	9.11309
Avg trace length	1.4303725	2.4278575	2.923816667	3.037696667

Test 2 P32 value	Box 1 dimensions 20x20x20 0.144082	Box 2 dimensions 10x40x20 0.137031	Box 3 dimensions 80x10x10 0.138266	Box 4 dimensions 32x10x25 0.146887
Traceplane 1	Box 1	Box 2	Box 3	Box 4
# of fractures	6	5	3	4
Total trace length	14.9033	14.6528	8.17856	11.5532
Avg trace length	2.483883333	2.93056	2.726186667	2.8883
Traceplane 2	Box 1	Box 2	Box 3	Box 4
# of fractures	10	7	6	10
Total trace length	23.9936	13.6946	16.062	24.5456

Avg trace length	2.39936	1.956371429	2.677	2.45456
Traceplane 3	Box 1	Box 2	Box 3	Box 4
# of fractures	5	4	3	1
Total trace length	11.4159	11.384	10.8416	2.06839
Avg trace length	2.28318	2.846	3.613866667	2.06839

February 4, 2005 DYW

EXPLANATION OF ASCII CONVERSION FORMULA

Testing to verify DOE input values for FracMan requires comparisons of orientation data both in Fracman and in Rockware StereoStat software. A small unix conversion code was written by N. Franklin to re-format the FracMan *.fab files to *.txt files for use in SteroeStat. The following is a detail of that code (fab2planes.awk).

```
#!/bin/sh
#
# ---------------------------------------------------------------------------
#   fab2planes.awk
#   abstract:   routine will change a fab file into a txt file of the planes
#                              (strike, dip) and the radius of the fracture
#
#   revised:
#   created:      Feb-2003
#
#                    Nathan Franklin / #20
#                    6220 culebra road
#                    san antonio tx 78238 usa
#                    E-mail: nfranklin@swri.edu
#                    Phone: 210-522-5207
# ---------------------------------------------------------------------------

if ( test $# -ne '2' ) then
    echo Usage: $0 "<infile.fab>" "<outfile.txt>"
    exit
fi

if ( test ! -f $1 ) then
    echo File: $1 not found.
    exit
fi

nawk ' BEGIN {
      garbage = ".garbage"
      bool bBeginFracture;
      bBeginFracture = 0;
      int fracNumber;
      int totalFracNumber;
      int nFractures;
      int readFractures;
      fracNumber = 0;
      readFractures = 0;
      totalFracNumber = -2;
      lineNumber = 0;
      double radius
      double x[7]; double y[7]; double z[7];
      int vertexNumber;
}
{
      if(lineNumber==0)
            print "#strike dip trend plunge radius" > output
      lineNumber++;
      if(bBeginFracture==0) {
            if( $1 == "No_Fractures" ) {
                  nFractures = $3;
                  print "reading .. " nFractures  " read"
            }

            if( substr($0,1,14) == "BEGIN FRACTURE" ) {
```

```
                bBeginFracture = 1;
            }
            if( substr($0,1,14) == "BEGIN Fracture" ) {
                bBeginFracture = 1;
            }
        }
        else if(bBeginFracture==1){
            if( substr($0,1,12) == "END FRACTURE" ) {
                bBeginFracture=0;
            }
            else if(fracNumber<=totalFracNumber  ){
                    if(NF!=4){
                        print "fracNumber=" fracNumber
                        print "ERROR on line " lineNumber;
                        print "NF = " NF;
                        print "bBeginFracture =" bBeginFracture;
                        exit;
                    }
                    else{
                        #print $2 " " $3 " " $4 > output
                        int vertexNumber;
                        vertexNumber = $1;
                        x[vertexNumber] = $2;
                        y[vertexNumber] = $3;
                        z[vertexNumber] = $4;
                        if(vertexNumber == totalFracNumber){
                            # Calculate  true normals
                          double deltBAx;
                          double deltBAy;
                          double deltBAz;
                          deltBAx = x[2] - x[1]
                          deltBAy = y[2] - y[1]
                          deltBAz = z[2] - z[1]

                          double deltCAx;
                          double deltCAy;
                          double deltCAz;
                          deltCAx = x[3] - x[1]
                          deltCAy = y[3] - y[1]
                          deltCAz = z[3] - z[1]


                          # Face normal components i j k
                            double i; double j; double k;
                            i=0.0;
                            j=0.0;
                            k=0.0;
                          i = (deltBAy *deltCAz) - (deltBAz * deltCAy);
                          j = -1 * (deltBAx * deltCAz - deltBAz *
deltCAx);
                          k = (deltBAx  *deltCAy) - (deltBAy *
deltCAx);

                          #make all the normal point towards the lower
hemisphere
                          if(k>0){
                            i *= -1;
                            j *= -1;
                            k *= -1;
                          }

                            #normalize all the normal vector
                            size = sqrt((i*i)+ (j*j) + (k*k));
```

```
                                        i = i /size;
                                        j = j /size;
                                        k = k /size;


                                        DTR = 0.0174532925;
                                        trend =  atan2(i,j) /DTR;
                                        if(trend < 0.0)
                                              trend = trend + 360.0;
                                        if(trend >= 360.0)
                                              trend = trend - 360.0;

                                        int sqroot;
                                        sqroot = (i*i) + (j*j);
                                        sqroot = sqrt(sqroot);

                                        plunge = 90 - atan2(k,sqroot)/ DTR;
                                        if(plunge > 90)
                                              plunge = 180- plunge;
                                        plunge = plunge - 90;


                                        strike = trend + 90;
                                        if(strike >= 360)
                                              strike = strike - 360.0;

                                        dip = 90 + plunge;

                                        plunge = -1 * plunge;

                                        print strike " " dip " " trend " " plunge
" " radius  > output
                                        readFractures++;
                                  }
                            }
                  }
                  else if($1==0){
                  }
                  else{
                        fracNumber=0;
                        totalFracNumber=$2;
                        radius=$7;
                        radius = radius + 0.0
                  }
                  fracNumber++;
      }
}
END {
      print "   read " readFractures " fractures"
    } ' output=$2 < $1
exit
```

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GS971108314224.021. Revision 1 of Detailed Line Survey Data, Station 4+00 to Station 8+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.022. Revision 1 of Detailed Line Survey Data, Station 8+00 to Station 10+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.023. Revision 1 of Detailed Line Survey Data, Station 10+00 to Station 18+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.024. Revision 1 of Detailed Line Survey Data, Station 18+00 to Station 26+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

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GS960708314224.008. Provisional Results: Geotechnical Data for Station 30+00 to Station 35+00, Main Drift of the ESF. Submittal date: 08/05/1996. *Data has been submitted to the TDMS and is currently being processed.* This data set has not been found as of Jan. 2004.

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GS970808314224.010. Provisional Results: Geotechnical Data for Station 70+00 to Station 75+00, South Ramp of the ESF. Submittal date: 08/25/1997.

GS970808314224.012. Provisional Results: Geotechnical Data for Station 75+00 to Station 78+77, South Ramp of the ESF. Submittal date: Submittal date: 08/25/1997.

GS990408314224.001. Detailed Line Survey Data for Stations 00+00.89 to 14+95.18, ECRB Cross Drift. Submittal Date: 09/09/1999.

GS990408314224.002. Detailed Line Survey Data for Stations 15+00.85 TO 26+63.8, ECRB Cross Drift. Submittal Date: 09/09/1999.

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GS990408314224.006. Full-Periphery Geologic Maps for Station 20+00 TO 26+81, ECRB Cross Drift. Submittal Date: 09/09/1999.

NOVEMBER 11, 2004 KJS

Appendix 1: Installation/Acceptance Test Memo for TurboCAD Deluxe (version 10.2)

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

MEMORANDUM

November 8, 2004

TO: Robert Brient, Director
Quality Assurance

FROM: Kevin J. Smart, Research Scientist
Geology & Geophysics

SUBJECT: Acceptance/Installation Test for *TurboCAD® Deluxe* (version 10.2)

TurboCAD® Deluxe (version 10.2) is marketed by IMSI, Inc., Novato, California and according to TOP-018 is classified as "Acquired Software -- Not To Be Modified." *TurboCAD®* was developed to provide a user-friendly computer aided design (CAD) tool.

TurboCAD® runs on all IBM PC-compatible computers (Windows 98/2000/NT 4.0/XP). It requires minimum of 64 MB of RAM, 55 to 212 MB hard disk space, and a Super VGA (1024x768) display. Currently, *TurboCAD®* is installed on "Petrel" in the GIS lab (A251). The installation was conducted by a member of the IMS staff.

The standard *TurboCAD®* installation provides thirty two 2D sample files and eleven 3D sample files that illustrate the capabilities of the software. All sample files were successfully opened into *TurboCAD®*. HTML-format help files are included with the standard installation.

At this time, I therefore recommend that *TurboCAD® Deluxe* (version 10.2) be considered to have successfully passed the acceptance/installation test requirements. If you have any questions, please do not hesitate to contact me.

Entries into Scientific Notebook No. 685E for the period 11/08/04 to 3/24/05 (pp. 1-19) have been made by K.J. Smart, P. Landis, and D. Wyrick. No original text entered into this Scientific Notebook has been removed.

Kevin J. Smart _____ Date 4/26/2011

I have reviewed this Scientific Notebook and find it in agreement with QAP-001. There is sufficient information regarding methods used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat this activity.

H. Lawrence McKague _____ Date 4/26/2011

for HOK

June 16, 2005 KJS

UPDATED SUMMARY OF FRACTURE STATISTICS

The following section updates and supercedes statistical analyses of DOE-collected fracture data that were originally documented by K.J. Smart in Scientific Notebook 606E. This update reflects a more complete analysis of fracture characteristics (e.g., orientation, spacing, tracelength) based upon fracture sets that were defined on the basis of stratigraphic interval and fracture orientation.

Table 1. Summary of fracture data from Topopah Spring middle nonlithophysal zone (Tptpmn) (excluding intensely fractured zone) based upon detailed line surveys in the ESF and ECRB, and calculations by K.J. Smart. This data was collected with a lower tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths >1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	6824, 100%	*n.a.*	*n.a.*	2.19	1.54	*n.a.*	*n.a.*	*n.a.*
1	3928, 58%	125°/85°	14.451	2.24	1.66	0.55	0.30	3.38
2	1835, 27%	217°/85°	4.684	1.97	1.40	0.81	0.37	2.73
3	545, 8%	327°/09°	29.131	2.68	1.64	0.96	0.49	2.02
Random	516, 8%	*n.a.*	*n.a.*	2.05	1.23	*n.a.*	*n.a.*	*n.a.*

Table 2. Summary of fracture data from Topopah Spring middle nonlithophysal zone (Tptpmn) (including intensely fractured zone) based upon detailed line surveys in the ESF and ECRB, and calculations by K.J. Smart. This data was collected with a lower tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths >1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	11387, 100%	*n.a.*	*n.a.*	2.19	1.66	*n.a.*	*n.a.*	*n.a.*
1	7767, 68%	128°/84°	19.617	2.24	1.78	0.48	0.18	5.57
2	2397, 21%	221°/85°	5.463	1.97	1.45	1.27	0.43	2.30
3	599, 5%	327°/09°	28.081	2.54	1.55	1.04	0.50	2.02
Random	624, 5%	*n.a.*	*n.a.*	1.99	1.24	*n.a.*	*n.a.*	*n.a.*

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Table 3. Summary of small-scale fracture data from Topopah Spring middle nonlithophysal zone (Tptpmn) based on two six-meter horizontal and six 2-meter vertical scanlines in the ECRB, and calculations by K.J. Smart. This data was collected with an upper tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths <1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	391, 100%	*n.a.*	*n.a.*	0.63	0.20	*n.a.*	*n.a.*	*n.a.*
1a	55, 14%	132°/87°	94.768	1.22	0.43	0.24	0.10	10.08
1b	59, 15%	100°/85°	21.741	0.97	0.30	0.19	0.09	10.75
2a	68, 17%	159°/87°	52.630	0.38	0.13	0.16	0.08	11.83
2b	47, 12%	179°/88°	1.643	0.24	0.14	0.19	0.08	13.05
2c	53, 14%	202°/88°	51.361	0.49	0.27	0.11	0.05	20.02
3	54, 14%	312°/05°	42.197	0.76	0.31	0.19	0.12	8.37
Random	55, 14%	*n.a.*	*n.a.*	0.33	0.17	*n.a.*	*n.a.*	*n.a.*

Table 4. Summary of fracture data from Topopah Spring lower lithophysal zone (Tptpll) based upon detailed line surveys in the ESF and ECRB, and calculations by K.J. Smart. This data was collected with a lower tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths >1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	338, 100%	*n.a.*	*n.a.*	4.04	1.92	*n.a.*	*n.a.*	*n.a.*
1	200, 59%	151°/82°	7.814	4.25	1.82	4.55	1.48	0.68
2a	47, 14%	205°/86°	26.076	3.82	1.90	8.18	4.09	0.24
2b	52, 15%	092°/85°	29.508	2.19	1.50	11.83	6.77	0.15
3	19, 6%	329°/05°	53.085	7.36	3.42	8.98	1.68	0.60
Random	20, 6%	*n.a.*	*n.a.*	4.88	2.78	*n.a.*	*n.a.*	*n.a.*

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Table 5. Summary of small-scale fracture data from the Topopah Spring lower lithophysal zone (Tptpll) based on three six-meter horizontal and nine 2-meter vertical scanlines in the ECRB, and calculations by K.J. Smart. This data was collected with an upper tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths <1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	649, 100%	*n.a.*	*n.a.*	0.31	0.16	*n.a.*	*n.a.*	*n.a.*
1	330, 51%	147°/84°	4.871	0.25	0.17	0.07	0.04	25.35
2a	30, 5%	202°/87°	33.034	0.22	0.19	0.36	0.17	6.75
2b	43, 7%	088°/85°	28.281	0.19	0.16	0.32	0.16	6.46
3	125, 19%	313°/04°	47.359	0.63	0.19	0.10	0.06	16.71
Random	121, 19%	*n.a.*	*n.a.*	0.20	0.13	*n.a.*	*n.a.*	*n.a.*

Table 6. Summary of fracture data from Topopah Spring lower nonlithophysal zone (Tptpln) based upon detailed line surveys in the ECRB, and calculations by K.J. Smart. This data was collected with a lower tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths >1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	199, 100%	*n.a.*	*n.a.*	4.04	1.93	*n.a.*	*n.a.*	*n.a.*
1a	96, 48%	134°/80°	48.804	3.85	2.06	2.18	0.75	1.33
2a	60, 30%	209°/85°	18.362	4.42	1.86	2.25	1.04	0.96
2b	22, 11%	170°/82°	9.091	5.70	2.28	9.18	5.52	0.18
3	16, 8%	337°/15°	67.639	1.55	1.31	2.75	1.59	0.63
Random	5, 3%	*n.a.*	*n.a.*	4.02	1.85	*n.a.*	*n.a.*	*n.a.*

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Table 7. Summary of fracture data from Topopah Spring upper lithophysal zone (Tptpul) based upon detailed line surveys in the ECRB and ESF, and calculations by K.J. Smart. This data was collected with a lower tracelength cut-off of 1 meter (i.e., sampled fractures with tracelengths >1 meter). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Tracelength (m)		True Spacing (m)		Median Intensity (m^{-1})
				Mean	Median	Mean	Median	
All	1578, 100%	*n.a.*	*n.a.*	2.61	1.36	*n.a.*	*n.a.*	*n.a.*
1a	258, 16%	121°/87°	26.134	2.20	1.44	3.38	1.17	0.85
2a	946, 60%	186°/85°	1.469	2.23	1.25	1.62	0.53	1.87
2b	138, 9%	311°/40°	2.333	5.75	3.30	4.10	2.21	0.45
3	62, 4%	329°/12°	19.716	5.43	3.88	3.53	1.20	0.83
Random	174, 3%	*n.a.*	*n.a.*	1.80	1.18	*n.a.*	*n.a.*	*n.a.*

Note: Set 2b has an intermediate dip of 40°.

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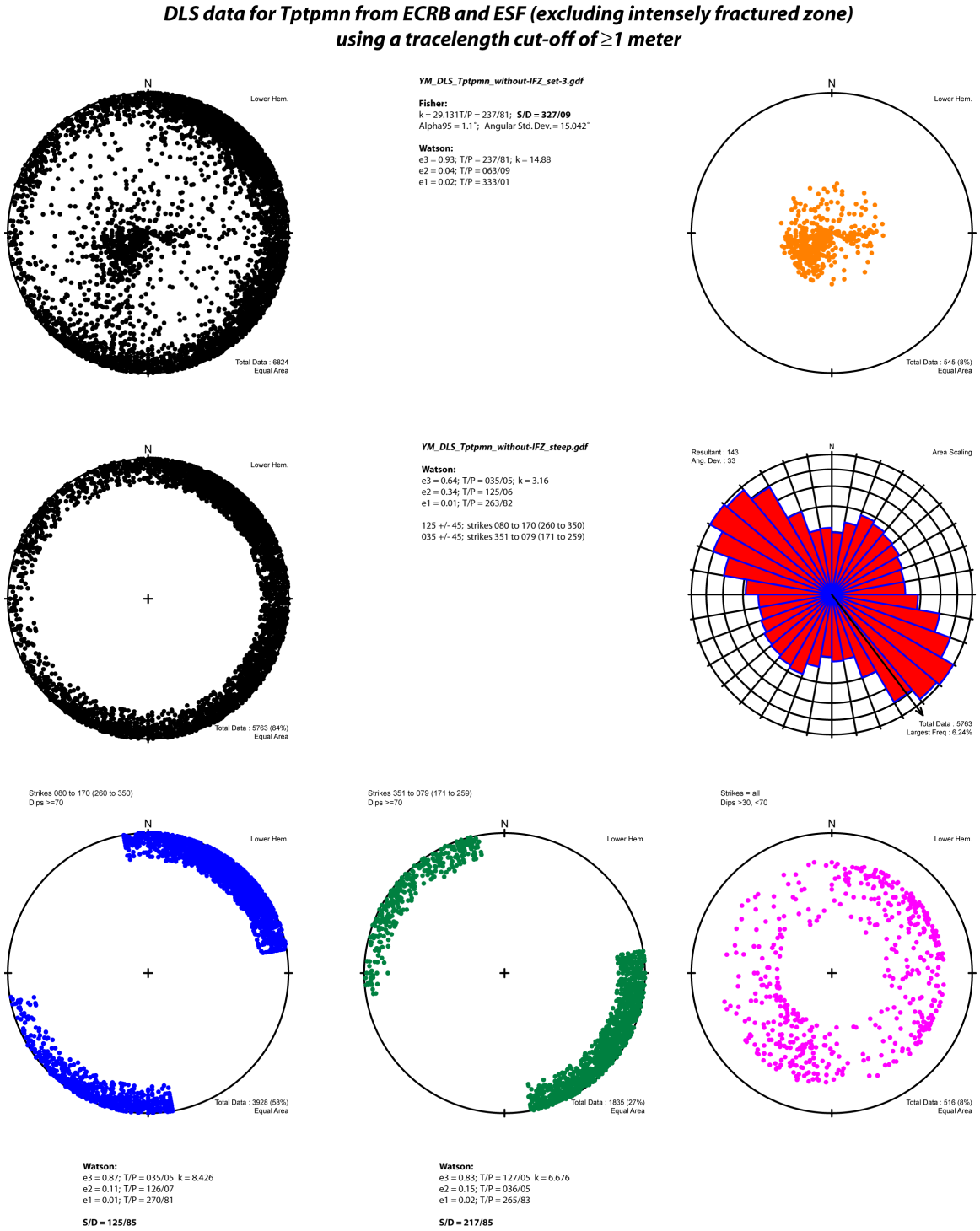

Figure 1. Summary of orientation data for fractures from the Tptpmn (excluding intensely fractured zone) collected via DLS in the ECRB and ESF using a lower tracelength cut-off of 1 meter. Refer to table 1 for full data details.

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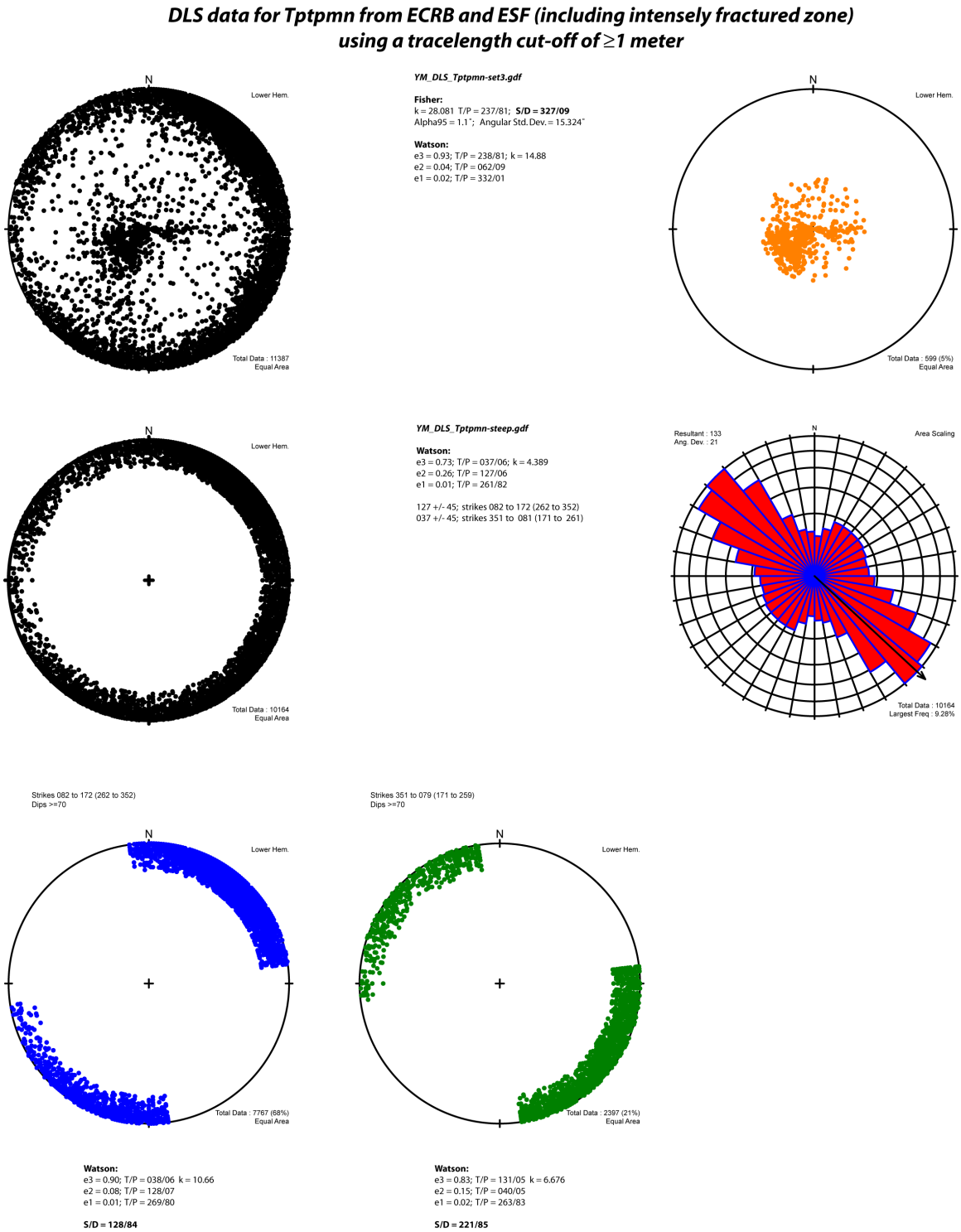

Figure 2. Summary of orientation data for fractures from the Tptpmn (excluding intensely fractured zone) collected via DLS in the ECRB and ESF using a lower tracelength cut-off of 1 meter. Refer to table 2 for full data details.

June 16, 2005 KJS

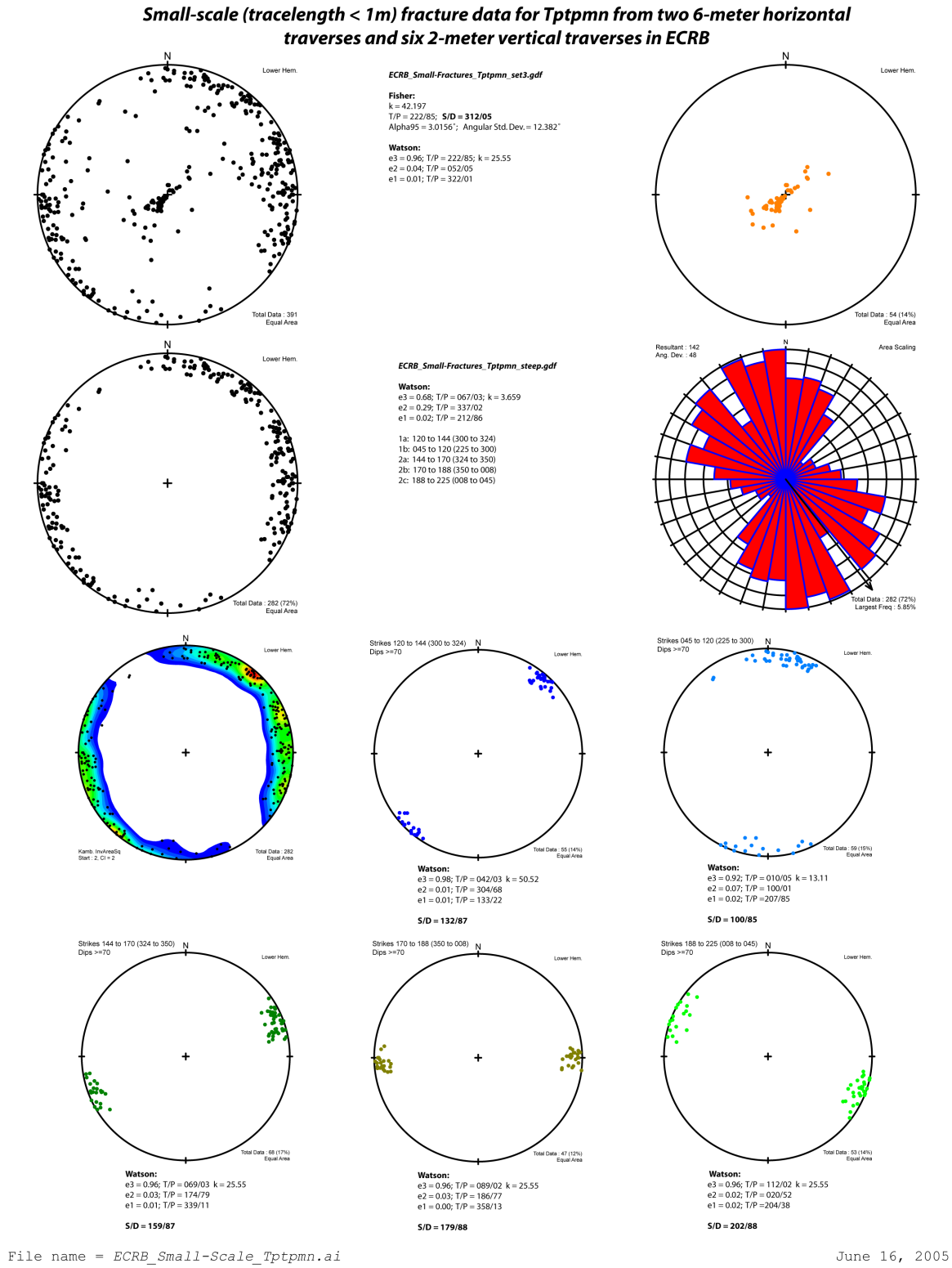

Figure 3. Summary of orientation data for small-scale fractures (upper tracelength cut-off of 1 meter) from Tptpmn collected via two 6-meter horizontal and six 2-meter vertical scanlines in the ECRB. Refer to table 3 for full data details.

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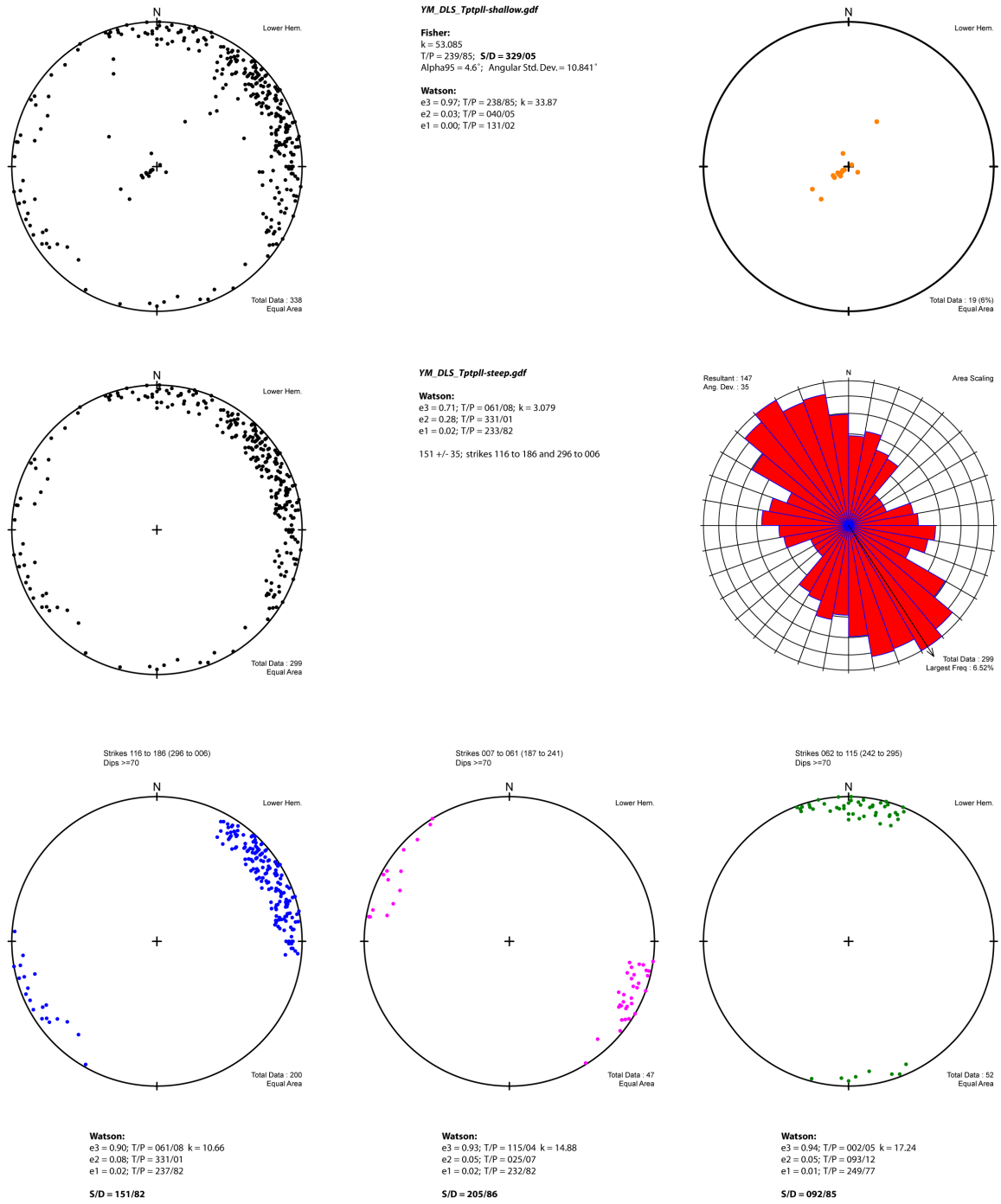
DLS data (tracelengths >1 meter) for Tptpll from ECRB and ESF



File name = *YM_DLS_Tptpll_summary.ai* June 16, 2005

Figure 4. Summary of orientation data for fractures from the Tptpll zone collected via DLS in the ECRB and ESF using a lower tracelength cut-off of 1 meter. Refer to table 4 for full data details.

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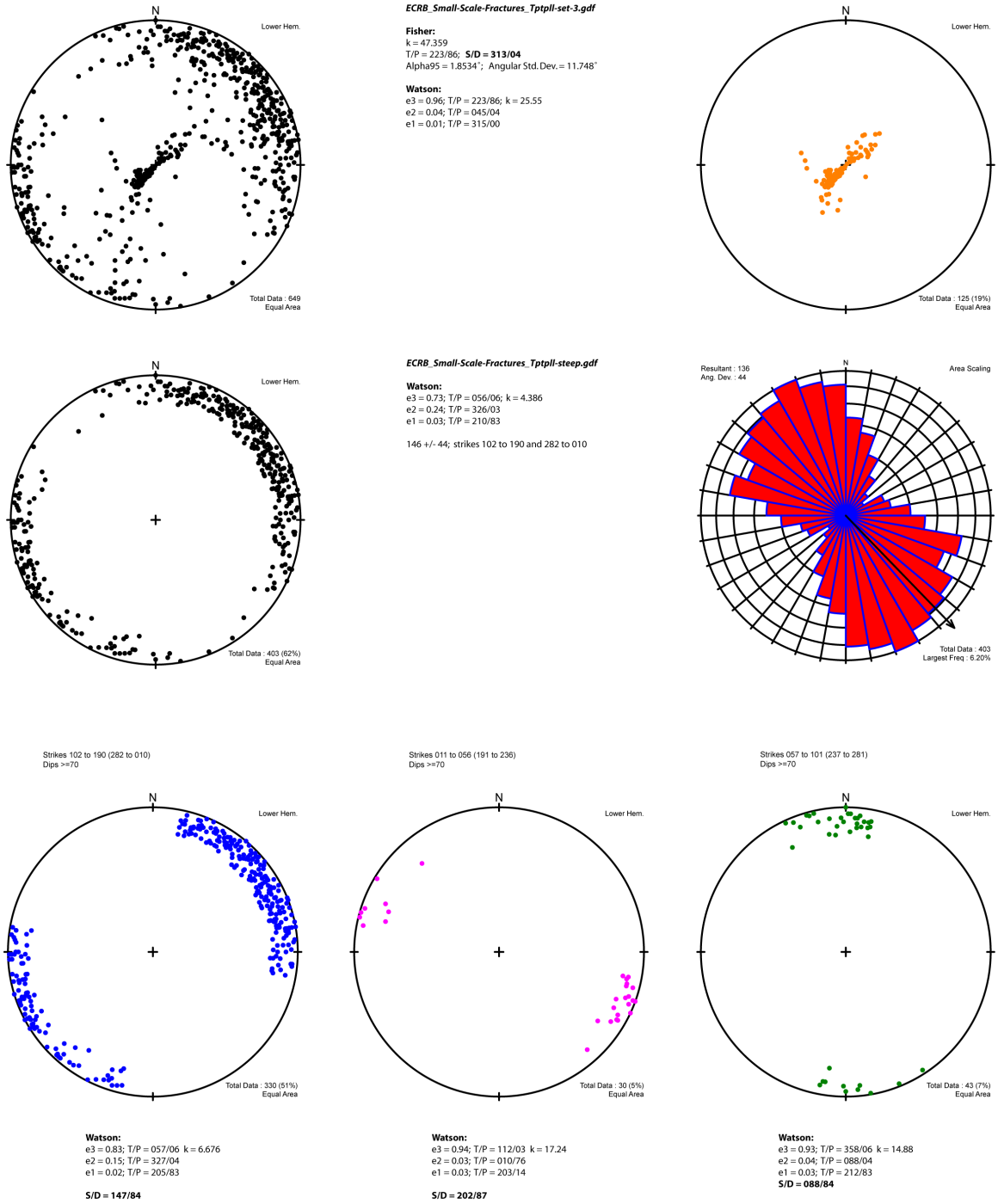
Small-scale (tracelength < 1m) fracture data for Tptpll from three 6-meter horizontal traverses and nine 2-meter vertical traverses in ECRB

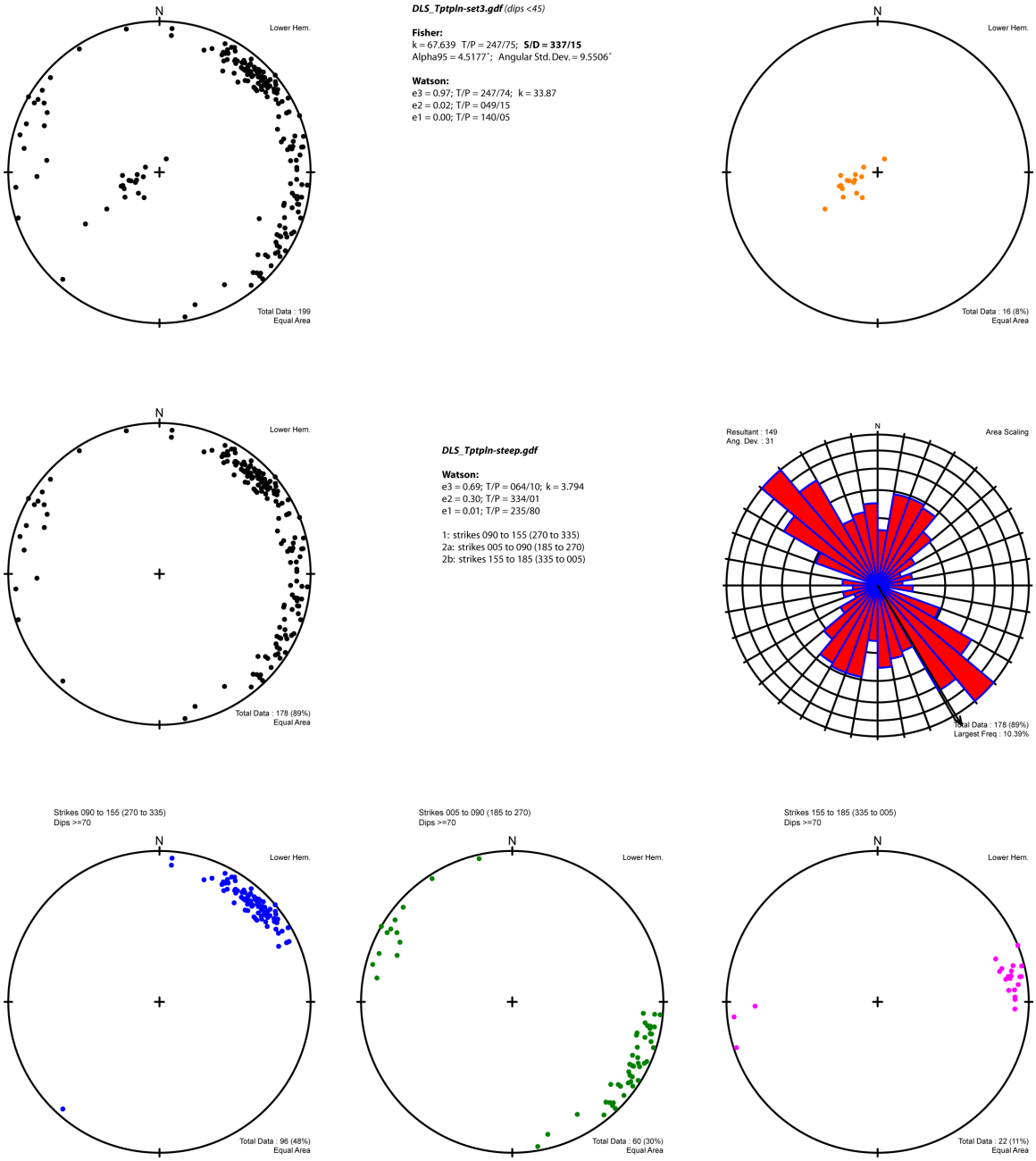


File name = *ECRB_Small-Scale_Tptpll.ai* June 16, 2005

Figure 5. Summary of orientation data for small-scale fractures (upper tracelength cut-off of 1 meter) from Tptpll collected via three 6-meter horizontal and nine2-meter vertical scanlines in the ECRB. Refer to table 5 for full data details.

June 16, 2005 KJS

DLS data for Tptpln from ECRB using a tracelength cut-off of ≥1 meter

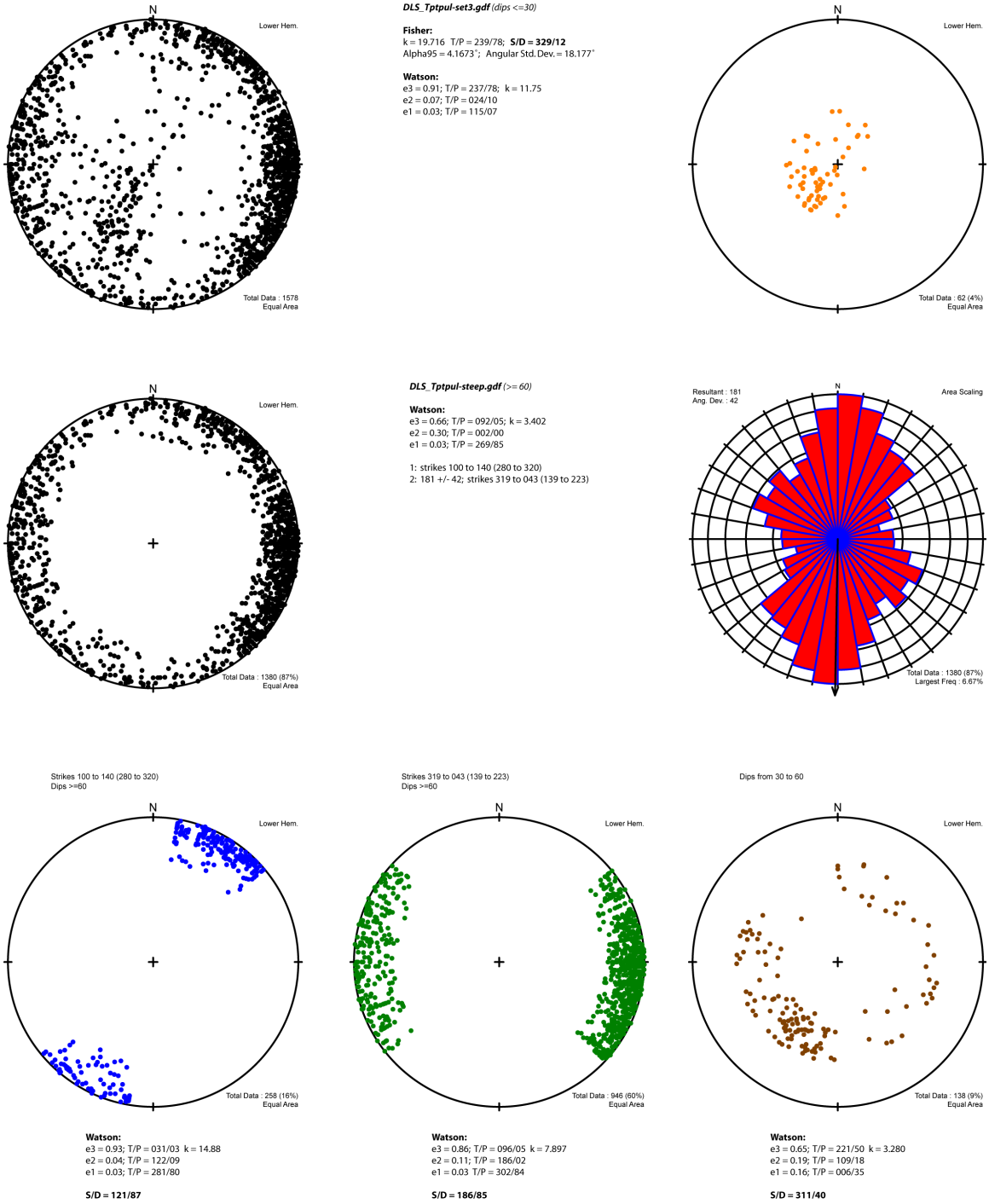


File name = *DLS_Tptpln_summary.ai* June 16, 2005

Figure 6. Summary of orientation data for fractures from the Tptpln zone collected via DLS in the ECRB using a lower tracelength cut-off of 1 meter. Refer to table 6 for full data details.

June 16, 2005 KJS

DLS data for Tptpul from ECRB and ESF using a tracelength cut-off of ≥1 meter



File name = *DLS_Tptpul_summary.ai* June 16, 2005

Figure 7. Summary of orientation data for fractures from the Tptpul zone collected via DLS in the ECRB and ESF using a lower tracelength cut-off of 1 meter. Refer to table 7 for full data details.

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August 15, 2005 KJS

REVISED SUMMARY OF FRACTURE STATISTICS

The following section revises and supercedes previous statistical analyses of DOE-collected fracture data. This update incorporates additional DOE fracture data files discovered during preparation of Intermediate Milestone IM 06002.01.292.510.

Table 1. Summary of fracture data from Topopah Spring Tuff Upper Lithophysal zone based upon detailed line surveys in the ECRB Cross-Drift and ESF. This data was collected with a lower trace length cut-off of 1 m [3.3 ft] (i.e., sampled fractures with trace lengths >1 m [3.3 ft]). True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	1758, 100%	*n.a.*	*n.a.*	2.56 [8.40]	1.42 [4.66]	*n.a.*	*n.a.*	*n.a.*
1	538, 31%	116°/85°	7.462	2.09 [6.86]	1.44 [4.72]	2.82 [9.25]	0.75 [2.46]	1.34 [0.41]
2	1024, 58%	181°/85°	1.945	2.29 [7.51]	1.30 [4.66]	1.73 [5.68]	0.65 [2.13]	1.53 [0.47]
3	95, 5%	320°/19°	9.436	5.73 [18.80]	4.31 [14.14]	3.98 [13.06]	1.29 [4.23]	0.77 [0.23]
Random	101, 6%	*n.a.*	*n.a.*	4.87 [15.98]	2.10 [6.89]	*n.a.*	*n.a.*	*n.a.*

Table 2. Summary of fracture data from Topopah Spring Tuff Middle Nonlithophysal zone (including intensely fractured zone) based upon detailed line surveys in the ESF and ECRB Cross-Drift. This data was collected with a lower trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	13493, 100%	*n.a.*	*n.a.*	2.12 [6.96]	1.58 [5.18]	*n.a.*	*n.a.*	*n.a.*
1	8919, 66%	126°/84°	17.670	2.18 [7.15]	1.70 [5.58]	0.42 [1.39]	0.19 [0.62]	5.20 [1.58]
2	2973, 22%	227°/86°	5.329	1.90 [6.23]	1.35 [4.43]	0.92 [3.02]	0.46 [1.51]	2.19 [0.67]
3	679, 5%	326°/08°	27.225	2.47 [8.10]	1.54 [5.05]	1.19 [3.90]	0.52 [1.71]	1.92 [0.59]
Random	922, 7%	*n.a.*	*n.a.*	2.02 [6.63]	1.27 [4.17]	*n.a.*	*n.a.*	*n.a.*

August 15, 2005 KJS

Table 3. Summary of fracture data from the intensely fractured zone in the Topopah Spring Tuff Middle Nonlithophysal zone based upon detailed line surveys in the ESF. This data was collected with a lower trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	4566, 100%	*n.a.*	*n.a.*	2.18 [7.15]	1.80 [5.91]	*n.a.*	*n.a.*	*n.a.*
1	3875, 85%	129°/84°	29.093	2.23 [7.32]	1.85 [6.07]	0.20 [0.66]	0.12 [0.39]	8.27 [2.52]
2	525, 11%	231°/87°	7.943	2.04 [6.69]	1.57 [5.15]	1.34 [4.40]	0.74 [2.43]	1.35 [0.41]
3	54, 1%	340°/07°	20.711	1.21 [3.97]	0.96 [3.15]	2.08 [6.82]	0.43 [1.41]	2.32 [0.71]
Random	112, 2%	*n.a.*	*n.a.*	1.73 [5.68]	1.37 [4.49]	*n.a.*	*n.a.*	*n.a.*

Table 4. Summary of fracture data from Topopah Spring Tuff Middle Nonlithophysal zone (excluding intensely fractured zone) based upon detailed line surveys in the ESF and ECRB Cross-Drift. This data was collected with a lower trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	8927, 100%	*n.a.*	*n.a.*	2.09 [6.86]	1.43 [4.69]	*n.a.*	*n.a.*	*n.a.*
1	5044, 57%	124°/85°	13.814	2.14 [7.02]	1.52 [4.99]	0.59 [1.94]	0.28 [0.92]	3.54 [1.08]
2	2448, 27%	226°/86°	4.994	1.87 [6.14]	1.30 [4.27]	0.84 [2.76]	0.41 [1.35]	2.41 [0.73]
3	625, 7%	326°/08°	27.979	2.58 [8.46]	1.61 [5.28]	1.09 [3.58]	0.53 [1.74]	1.89 [0.58]
Random	810, 9%	*n.a.*	*n.a.*	2.07 [6.79]	1.27 [4.17]	*n.a.*	*n.a.*	*n.a.*

August 15, 2005 KJS

Table 5. Summary of small-scale fracture data from Topopah Spring Tuff Middle Nonlithophysal zone based on two 6-meter [20 ft] horizontal and six 2-meter [7 ft] vertical scanlines in the ECRB Cross-Drift. This data was collected with an upper trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	391, 100%	*n.a.*	*n.a.*	0.63 [2.07]	0.20 [0.66]	*n.a.*	*n.a.*	*n.a.*
1	164, 42%	179°/88°	14.449	0.38 [1.25]	0.15 [0.49]	0.07 [0.23]	0.04 [0.13]	26.10 [7.95]
2	118, 30%	118°/86°	15.514	1.06 [3.48]	0.30 [0.98]	0.11 [0.36]	0.07 [0.23]	15.31 [4.67]
3	54, 14%	312°/05°	42.197	0.76 [2.49]	0.31 [1.02]	0.19 [0.62]	0.12 [0.39]	8.37 [2.55]
Random	55, 14%	*n.a.*	*n.a.*	0.33 [1.08]	0.17 [0.56]	*n.a.*	*n.a.*	*n.a.*

Table 6. Summary of fracture data from Topopah Spring Tuff Lower Lithophysal zone based upon detailed line surveys in the ESF and ECRB Cross-Drift. This data was collected with a lower trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	338, 100%	*n.a.*	*n.a.*	4.04 [13.26]	1.92 [6.30]	*n.a.*	*n.a.*	*n.a.*
1	254, 75%	158°/81°	2.606	4.21 [13.81]	1.88 [6.19]	3.48 [11.42]	1.39 [4.56]	0.72 [0.22]
2	60, 18%	087°/85°	17.759	2.32 [7.61]	1.63 [5.35]	9.07 [29.76]	6.17 [20.24]	0.16 [0.05]
3	19, 6%	329°/05°	53.085	7.36 [24.15]	3.42 [11.22]	4.59 [15.06]	1.39 [4.56]	0.72 [0.22]
Random	5, 1%	*n.a.*	*n.a.*	3.16 [10.37]	3.55 [11.65]	*n.a.*	*n.a.*	*n.a.*

August 15, 2005 KJS

Table 7. Summary of small-scale fracture data from the Topopah Spring Tuff Lower Lithophysal zone based on three 6-meter [20 ft] horizontal and nine 2-meter [7 ft] vertical scanlines in the ECRB Cross-Drift. This data was collected with an upper trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	649, 100%	*n.a.*	*n.a.*	0.31 [1.02]	0.16 [0.52]	*n.a.*	*n.a.*	*n.a.*
1	421, 65%	134°/82°	3.344	0.25 [0.82]	0.17 [0.56]	1.08 [3.54]	0.03 [0.10]	27.56 [8.40]
2	49, 8%	079°/82°	14.633	0.19 [0.62]	0.14 [0.50]	0.24 [0.79]	0.12 [0.39]	8.39 [2.56]
3	125, 19%	313°/04°	47.359	0.63 [2.07]	0.19 [0.62]	0.10 [0.33]	0.06 [0.20]	16.71 [5.09]
Random	54, 8%	*n.a.*	*n.a.*	0.17 [0.56]	0.12 [0.39]	*n.a.*	*n.a.*	*n.a.*

Table 8. Summary of fracture data from Topopah Spring Tuff Lower Nonlithophysal zone based upon detailed line surveys in the ECRB Cross-Drift. This data was collected with a lower trace length cut-off of 1 m [3.3 ft]. True spacing reflects correction of orientation bias using a truncated Terzaghi approach (i.e., Terzaghi, 1965). Median intensity is the inverse of median fracture spacing (equivalent to number of fractures per unit length of scanline).

Set	Number & Percentage	Mean Orientation	Fisher dispersion coefficient	Total Trace Length, m [ft]		True Spacing, m [ft]		Median Intensity, m^{-1} [ft^{-1}]
				Mean	Median	Mean	Median	
All	199, 100%	*n.a.*	*n.a.*	4.04 [13.26]	1.93 [6.33]	*n.a.*	*n.a.*	*n.a.*
1	121, 61%	134°/80°	48.804	4.39 [14.40]	2.25 [7.38]	1.89 [6.20]	0.73 [2.40]	1.37 [0.42]
2	61, 31%	209°/85°	18.362	4.05 [13.29]	1.66 [5.45]	1.79 [5.87]	0.70 [2.30]	1.42 [0.43]
3	16, 8%	337°/15°	67.639	1.55 [5.09]	1.31 [4.30]	2.75 [9.02]	1.59 [5.22]	0.63 [0.19]
Random	1, <1%	*n.a.*	*n.a.*	1.85 [6.07]	1.85 [6.07]	*n.a.*	*n.a.*	*n.a.*

August 16, 2005 DYW

FRACMAN MODEL RUNS FOR TptpII

Two sets of models were performed for the TptpII. These model runs were named II_FM_DOE_input_test1-random.fwk, using a randomly generated seed number, and II_FM_DOE_input_test2-seed725.fwk, using the DOE provided seed number of 725. Within the FracMan software, a model was setup using the parameters specified in Figure B-3 of the Drift Degradation Analysis (ANL-EBS-MD-000027 REV03). Six distinct fracture sets were input into the models and various tests were performed.

VERIFICATION OF ORIENTATION AND DISPERSION OF FRACTURES

The FracMan generated fractures were exported from FracMan as *.fab files (e.g., fracs_test1_set1.fab). Using the shell script fab2planes.awk (detailed earlier in notebook), the files were converted to *.txt. These files were then imported into Rockware StereoStat and used to calculate the fracture orientation and dispersion (k value). The following values were derived for tests 1 and 2:

StereoStat Results, Test 1
22jun05, dyw

FILE: fracs_test1_set1.txt
Average orientation: (azimuth, plunge) (238,76)
KValue: 72.95
FM INPUT VALUES: (239,76) K=70

FILE: fracs_test1_set2.txt
Average orientation: (azimuth, plunge) (040,10)
KValue: 69.294
FM INPUT VALUES: (040,10) K=70

FILE: fracs_test1_set3.txt
Average orientation: (azimuth, plunge) (076,10)
KValue: 63.442
FM INPUT VALUES: (085,10) K=70

FILE: fracs_test1_set4.txt
Average orientation: (azimuth, plunge) (040,10)
KValue: 99.104
FM INPUT VALUES: (040,10) K=100

FILE: fracs_test1_set5.txt
Average orientation: (azimuth, plunge) (080,10)
KValue: 100.84
FM INPUT VALUES: (085,10) K=100

FILE: fracs_test1_set6.txt
Average orientation: (azimuth, plunge) (008,05)
KValue: 102.25
FM INPUT VALUES: (008,05) K=100

StereoStat Results, Test 2

24jun05, dyw

FILE: fracs_test2_set1.txt
Average orientation: (azimuth, plunge) (238,76)
KValue: 72.95
FM INPUT VALUES: (239,76) K=70

FILE: fracs_test2_set2.txt
Average orientation: (azimuth, plunge) (040,10)
KValue: 69.294
FM INPUT VALUES: (040,10) K=70

FILE: fracs_test2_set3.txt
Average orientation: (azimuth, plunge) (077,10)
KValue: 68.625
FM INPUT VALUES: (085,10) K=70

FILE: fracs_test2_set4.txt
Average orientation: (azimuth, plunge) (040,10)
KValue: 100.16
FM INPUT VALUES: (040,10) K=100

FILE: fracs_test2_set5.txt
Average orientation: (azimuth, plunge) (081,10)
KValue: 99.334
FM INPUT VALUES: (085,10) K=100

FILE: fracs_test2_set6.txt
Average orientation: (azimuth, plunge) (008,05)
KValue: 104.13
FM INPUT VALUES: (008,05) K=100

All values were within the predefined range of acceptance. There was a minor correction done to the fracture dispersion values, due to the software's inability to calculate dispersion values within certain orientation ranges. The following notes document the corrections made.

```
**********************************************************************
StereoStat derived k values from fracs_test1_setX.fab/txt

These files are from synthetic fractures generated in FracMan using:
1) a random seed number (Test 1)
2) DOE seed #725 (Test 2), per figure B-3 of the Drift Degradation Analysis
 (ANL-EBS-MD-000027, REV03; Sept 2004)

The *.txt files were imported into StereoStat to derive fracture statistics.
**********************************************************************
Currently the files fracs_test1_set3.txt and fracs_test1_set5.txt are
generating unusual statistics in the dispersion (k) value.  This may be due to
their orientation.  A series of tests should be performed, e.g. rotating the
entire data set around a vertical axis, to determine if this a real problem
with the data set or merely a bug in the software that can be worked around.
dyw
23jun05
**********************************************************************
The same error has occurred for the fracs_test2_set3.txt and
fracs_test2_set5.txt. The most likely culprit is a glitch in the software that
is unable to calculate k values on this data set due to the orientation.
```

```
Further tests are currently being performed to constrain the problem.
dyw
24jun05
**********************************************************************
The data set statistics can be generated by essentially running the data twice
-- once to derive orientation (azimuth data) and then rotating the entire data
set -45˚ to derive k.  The software has a problem determining the k value for
this particular orientation.  The following statistics were generating using
this method.  The k value is used on the rotated data and the orientation is
used on the regular data.
dyw
28jun05

fracs_test1_set3.txt rotated
(40,10) k=63.442
fracs_test1_set3.txt
(76,10) k=2.0438

fracs_test1_set5.txt rotated
(40,10) k=100.84
fracs_test1_set5.txt
(80,10) k=2.6725

fracs_test2_set3.txt rotated
(40,10) k=68.625
fracs_test2_set3.txt
(77,10) k=2.2051

fracs_test2_set5.txt rotated
(40,10) k=99.334
fracs_test2_set5.txt
(81,10) k=2.9848
**********************************************************************
```

NOTE: The software still has a software glitch, so a series of functions must be performed in this order to get all the statistics:
1) Open StereoStat
2) Open *.txt file and assign column headers as normal
3) Plot Stereonet of data (Plot->Stereonet->Plot fault lineations only)
4) Close plot
5) Rotate data (Data->Rotate Data->Rotate entire dataset; Vertical axis; -45 deg)
6) Plot Stereonet of rotated data (see above)
7) Close plot
8) With rotated dataset selected, Analyze Data (Data Analysis->Analyze Data->Analyze Faults; donot Add results to dataset; click Fisher axis Options; select Treat data as axes)
9) Repeat step 8 with the regular data set

BOREHOLE RESULTS TO DERIVE P10 FRACTURE DENSITY VALUES

A series of boreholes were “drilled” into the fracture model volume to derive fracture density (P10, number of fractures per unit length). The following SAB file was created and imported into FracMan (9_boreholes_1m.SAB). It creates nine evenly spaced boreholes with a length of 100 m and a radius of 1 m. The boreholes are oriented with a trend and plunge to mimic the orientation of the DLS data (071,00). They are situated well within the defined model region to avoid artificial cropping at the model edge.

```
BEGIN borehole_simple
    name = "Borehole 1"
```

```
    origin =       -45.000        -45.0        .000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 2"
    origin =       -45.000        -25.0        .000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 3"
    origin =       -45.000        -5.0        .000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 4"
    origin =       -45.000        -45.0        20.000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 5"
    origin =       -45.000        -25.0        20.000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 6"
    origin =       -45.000        -5.0        20.000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 7"
    origin =       -45.000        -45.0        -20.000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 8"
    origin =       -45.000        -25.0        -20.000
```

```
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END

BEGIN borehole_simple
    name = "Borehole 9"
    origin =       -45.000        -5.0        -20.000
    trend  =      71.000
    plunge =      0.000
    radius =        1.0
    length =     100
END
```

After importing the borehole SAB file into the FracMan model, select Analysis->Exploration->Borehole. Borehole sampling was done on each individual fracture set and on the entire model fracture sets. Results are summarized in the supplemental files BH_FM_DOE_fracs_test1-random_all-sets.xls and BH_FM_DOE_fracs_test2-seed725_all-sets.xls. The following corrections were made to the borehole results:

```
**********************************************************************
BH_FM_DOE_fracs_test2-seed725_all-sets

The FracMan generation of 'seed725' fractures contains 6 sets of fractures.
Set 6 has a very small fracture density input value and small fracture radius.
When drilling exploration boreholes in the fracture set 6, none of the
boreholes encounters a fracture. As such, no statistics are being compiled by
the software. An export set6.sts file was not generated by FracMan.  Instead,
I have replicated the export file, substituting zeros for the Intensity P10
values, and filling in all other fracture data from information within the
FracMan project.
dyw
23jun05
**********************************************************************
```

FRACTURE RADIUS DISTRIBUTION RESULTS

The exported fracture files (e.g., fracs_test1_set1.txt) were imported into Excel to plot frequency versus fracture radius histogram plots. The fracture size was binned in increments of 0.5 m and plotted for each individual fracture set and the combined model fractures. The results are summarized in the supplemental files ll_FM_DOE_input_test1-random_all-sets.xls and ll_FM_DOE_input_test2-seed725_all-sets.xls.

TUNNEL RESULTS TO DERIVE P21 FRACTURE DENSITY VALUES

A series of tunnels were “drilled” into the fracture model volume to derive fracture density (P20, number of fractures per unit area and P21, total fracture length per unit area). The following SAB file was created and imported into FracMan (tunnel-5_90m.SAB). It creates five tunnels with a length of 90 m with a radius of 5.5 m. The tunnels consist of seven panels arranged in an octagon shaped tunnel with the floor (the eight panel) deleted to closely mimic the FPGM data sets. The tunnels are evenly spaced throughout the model region and oriented with a trend and plunge similar to the DLS data (071,00). They are situated well within the defined region to avoid artificial cropping at the model edge.

```
BEGIN COORDinate_system
```

```
    XAxis = East
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_1-90"
    origin = -45 -44.235 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_2-90"
    origin = -45 -42.5 2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_3-90"
    origin = -45 -40.765 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_4-90"
    origin = -45 -40 0
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 90
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_5-90"
    origin = -45 -40.765 -1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_6-90"
    origin = -45 -42.5 -2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
```

```
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_bottom_traceplane_7-90"
    origin = -45 -44.235 -1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_1"
    origin = -45 -24.235 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_2"
    origin = -45 -22.5 2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_3"
    origin = -45 -20.765 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_4"
    origin = -45 -20 0
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 90
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_5"
    origin = -45 -20.765 -1.7775
    scan_trend = 71
```

```
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_6"
    origin = -45 -22.5 -2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_center_traceplane_7"
    origin = -45 -24.235 -1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_1"
    origin = -45 -4.235 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_2"
    origin = -45 -2.5 2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_3"
    origin = -45 -.765 1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_4"
```

```
    origin = -45 0 0
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 90
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_5"
    origin = -45 -.765 -1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_6"
    origin = -45 -2.5 -2.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_top_traceplane_7"
    origin = -45 -4.235 -1.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_1"
    origin = -45 -24.235 21.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_2"
    origin = -45 -22.5 22.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END
```

```
BEGIN traceplane
    name = "Tunnel_left_traceplane_3"
    origin = -45 -20.765 21.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_4"
    origin = -45 -20 20
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 90
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_5"
    origin = -45 -20.765 18.2225
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_6"
    origin = -45 -22.5 17.4575
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_left_traceplane_7"
    origin = -45 -24.235 18.2225
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_1"
    origin = -45 -24.235 -18.2225
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
```

```
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_2"
    origin = -45 -22.5 -17.4575
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_3"
    origin = -45 -20.765 -18.2225
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_4"
    origin = -45 -20 -20
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 90
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_5"
    origin = -45 -20.765 -21.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = -45
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_6"
    origin = -45 -22.5 -22.5425
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
    tran_plunge = 0
    tran_width = 2.16
END

BEGIN traceplane
    name = "Tunnel_right_traceplane_7"
    origin = -45 -24.235 -21.7775
    scan_trend = 71
    scan_plunge = 0
    scan_length = 90
    tran_trend = 0
```

```
    tran_plunge = 45
    tran_width = 2.16
END
```

Fracture tracelength data was extracted for each fracture set and the total fracture sets by selecting Analysis->Exploration->Traceplane. All seven traceplanes were highlighted that constitute the tunnel. The data was then imported into Excel and is summarized in the files ll_Tunnels_all-frac-sets_test1-random.xls and ll_Tunnels_all-frac-sets_test2-seed725.xls.

Calculations performed in Excel versus FracMan had a small variance. The following notes document the discrepancy:

```
*******************************************************************
Tunnel traceplanes

There is a discrepancy between the area that FracMan calculates for the area
of a traceplane and hand calculations of the area. Specifically, the
traceplane is 2.16m wide and 90m long.  Visual checks all indicate that the
traceplane is well within the box region and is not being artificially
truncated by the box.  However, the program calculates the area differently
for each trace plane. There seems to be a correlation between the angle of the
transverse plunge and the area calculated.  Traceplanes with the same length,
width, trend *and* antithetical plunge values that are the same (e.g., one
plane dipping at 45˚ and the other at -45˚) have the same area calculated.
This value however is slightly less than the area determined by hand
calculations (e.g., 2.16*90=194.4).  A traceplane with a transverse plunge of
90˚ gives the most accurate area.

Will continue to pursue this matter.
dyw
01jul05
*******************************************************************
A series of calculations was performed to determine what effect, if any, the
small variance in the traceplane area would have on the overall fracture
density values.  When calculating P21 density, the small difference in area
from FracMan and Excel calculations amounts to a difference of less than
0.003.  This small amount is not sufficient in the fracture density analysis,
so the values derived from FracMan will be used as generated.
dyw
15jul05
*******************************************************************
```

FRACMAN MODEL RUNS FOR Tptpmn

Two sets of models were performed for the Tptpmn. These model runs were named mn_FM_DOE_input_test1-random.fwk, using a randomly generated seed number, and mn_FM_DOE_input_test2-seed1.fwk, using the DOE provided seed number of 001. Within the FracMan software, a model was setup using the parameters specified in Figure 6-18 of the Drift Degradation Analysis (ANL-EBS-MD-000027 REV03). Seven distinct fracture sets were input into the models and various tests were performed. The tests were identical in nature to the tests performed for the Tptpll unit and are summarized in the supplemental files.

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REVISED SUMMARY OF FRACTURE STATISTICS (continued from page 36)

Spreadsheets containing fracture data are listed in the following file (README.RTF) that is included on the CD with the spreadsheets:

```
K.J. Smart
August 15, 2005


File listing for spreadsheets used for fracture synthesis report (IM
06002.01.292.510):

(1) DLS_Fracture-Type_PIE.xls --> Detailed line survey (DLS) data on fracture type as
recorded in ESF and ECRB.

(2) DLS_Tptpll.xls --> DLS data for Topopah Spring Tuff Lower Lithophysal zone as
recorded in ESF and ECRB.

(3) DLS_Tptpln.xls --> DLS data for Topopah Spring Tuff Lower Nonlithophysal zone as
recorded in ESF and ECRB.

(4) DLS_Tptpmn_All.xls --> DLS data for all fractures from Topopah Spring Tuff Middle
Nonlithophysal zone as recorded in ESF and ECRB.

(5) DLS_Tptpmn_IFZ-only.xls --> DLS data for intensely fractured zone (IFZ) from the
Topopah Spring Tuff Middle Nonlithophysal zone in the ESF.

(6) DLS_Tptpmn_wo-IFZ.xls --> DLS data for fractures (excluding the IFZ in the ESF)
from Topopah Spring Tuff Middle Nonlithophysal zone as recorded in ESF and ECRB.

(7) DLS_Tptpul.xls --> DLS data for Topopah Spring Tuff Upper Lithophysal zone as
recorded in ESF and ECRB.

(8) ECRB_DLS_Fractures_All.xls --> DLS data for all fractures recorded in the ECRB.

(9) ECRB_FPGM_Tptpll_orientations.xls --> Full-periphery geologic mapping (FPGM) data
for fracture orientations from the Topopah Spring Tuff Lower Lithophysal zone from
the ECRB.

(10) ECRB_FPGM_Tptpln_orientations.xls --> FPGM data for fracture orientations from
the Topopah Spring Tuff Lower Nonlithophysal zone from the ECRB.

(11) ECRB_FPGM_Tptpmn_orientations.xls --> Full-periphery geologic mapping (FPGM)
data for fracture orientations from the Topopah Spring Tuff Middle Nonlithophysal
zone from the ECRB.

(12) ECRB_FPGM_Tptpul_orientations.xls --> Full-periphery geologic mapping (FPGM)
data for fracture orientations from the Topopah Spring Tuff Upper Lithophysal zone
from the ECRB.

(13) ESF_DLS_Fractures_All.xls --> DLS data for all fractures recorded in the ESF.

(14) ESF_FPGM_Fractures_All.xls --> FPGM data for all fracture orientations from the
ESF.

(15) Small-Scale-Fracture-Data_Tptpll --> DLS data for small-scale fracture study in
the Topopah Spring Tuff Lower Lithophysal zone as recorded in ECRB.

(16) Small-Scale-Fracture-Data_Tptpmn --> DLS data for small-scale fracture study in
the Topopah Spring Tuff Middle Nonlithophysal zone as recorded in ECRB.
```

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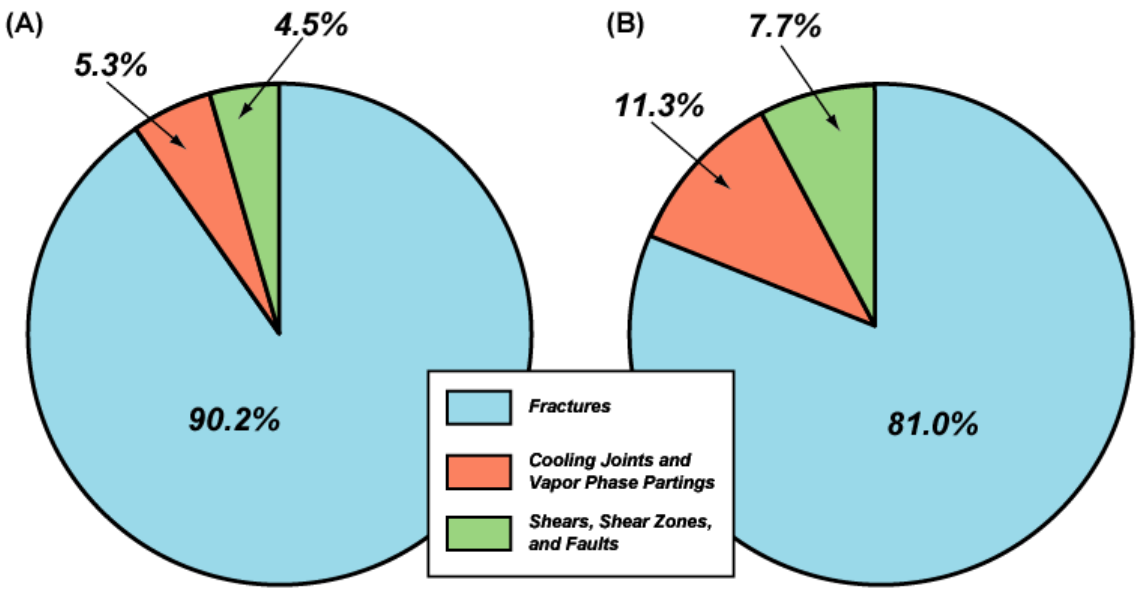

Figure 1. Distribution of fractures by type as recorded by detailed line survey in the (A) ESF and (B) the ECRB Cross-Drift.

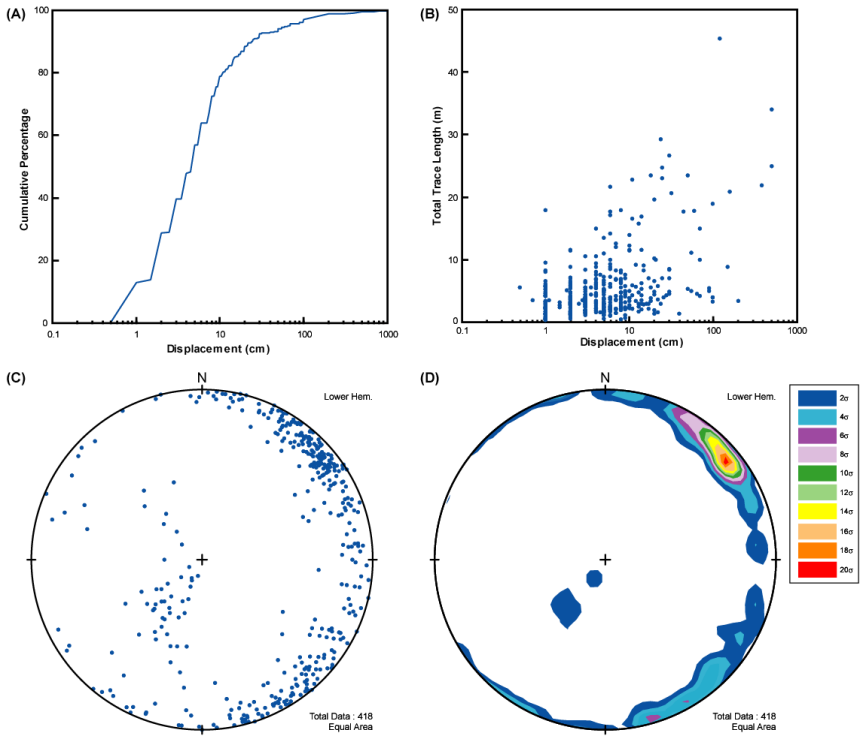

Figure 2. Summary of fractures with recorded displacement based upon detailed line survey in the ESF. (A) Displacement versus cumulative percentage. (B) Comparison of total trace length versus displacement. (C) Equal-area stereonet plot of fracture poles. (D) Contours of poles to fracture planes calculated with the 1% area method (Knopf and Ingerson, 1938; Turner and Weiss, 1963).

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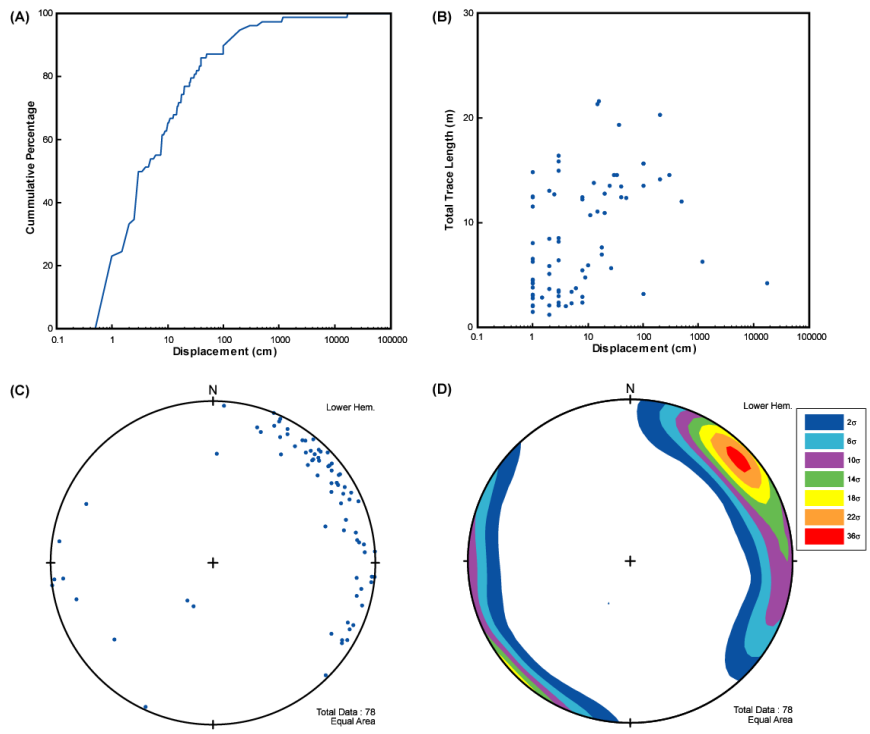

Figure 3. Summary of fractures with recorded displacement based upon detailed line survey in the ECRB Cross-Drift. (A) Displacement versus cumulative percentage. (B) Comparison of total trace length versus displacement. (C) Equal-area stereonet plot of fracture poles. (D) Contours of poles to fracture planes calculated with the Kamb method (Kamb, 1959). The Kamb contouring method was used because the 1% method is not appropriate for data sets smaller than approximately 300 points.

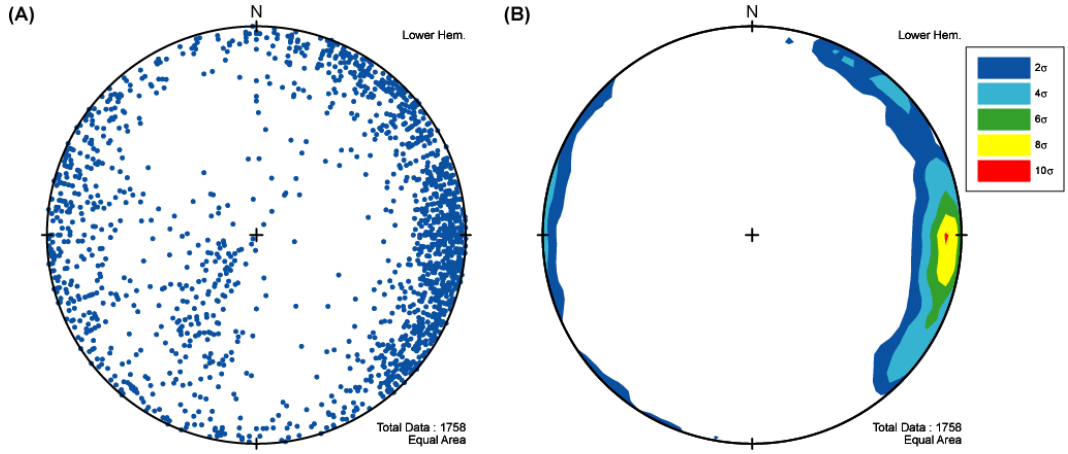

Figure 4. Orientation summary for fractures from the Topopah Spring Tuff Upper Lithophysal zone recorded by detailed line survey in the ESF and the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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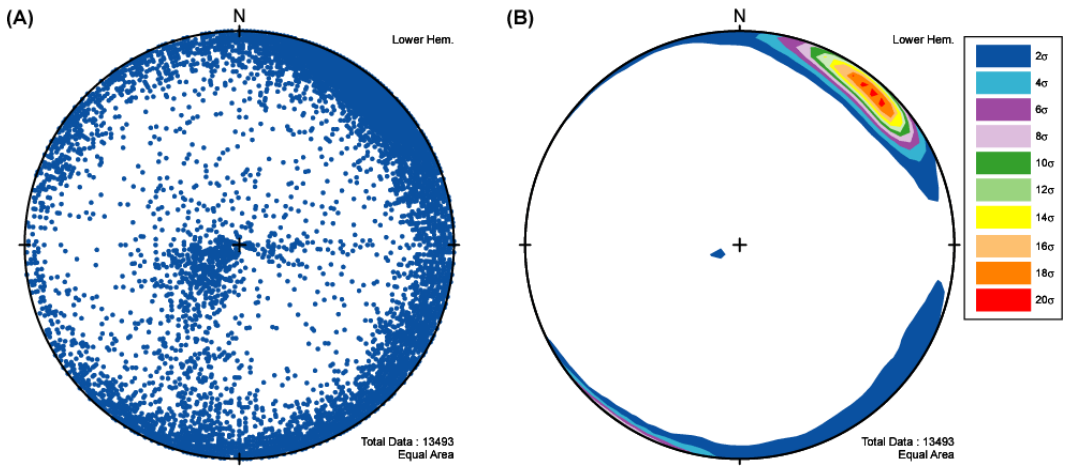

Figure 5. Orientation summary for fractures from the Topopah Spring Tuff Middle Nonlithophysal zone (including the intensely fractured zone) recorded by detailed line survey in the ESF and the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

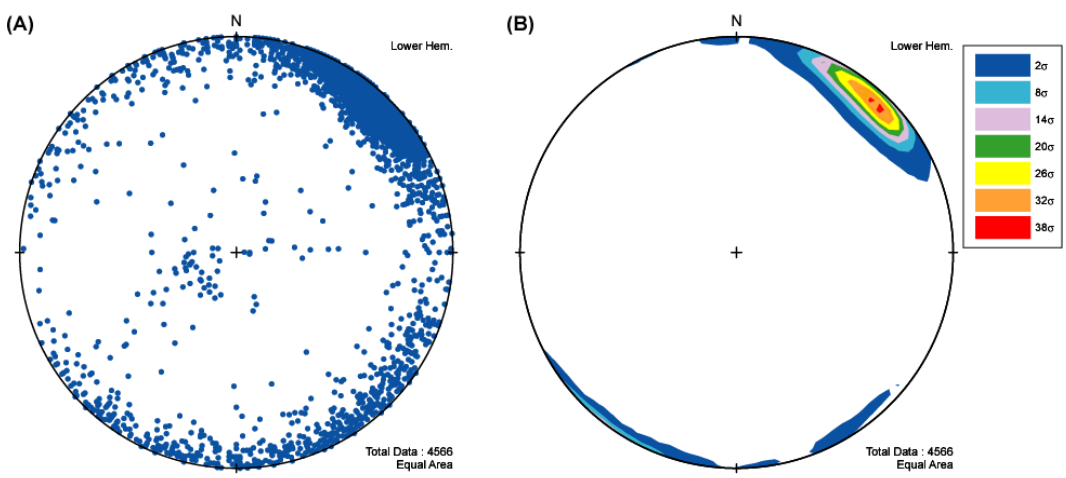

Figure 6. Orientation summary for fractures from the intensely fractured zone within the Topopah Spring Tuff Middle Nonlithophysal zone recorded by detailed line survey in the ESF (stations 42+00 to 51+50). (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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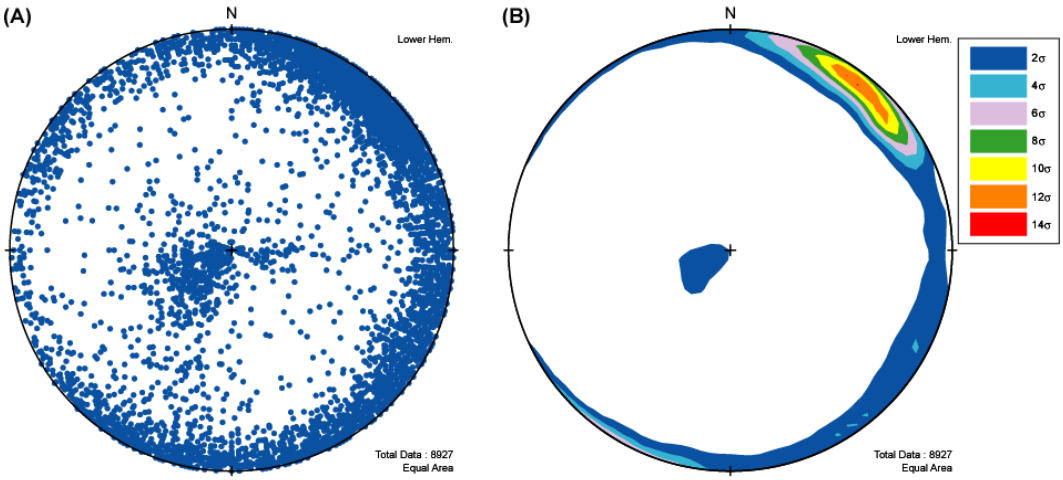

Figure 7. Orientation summary for fractures from the Topopah Spring Tuff Middle Nonlithophysal zone (excluding the intensely fractured zone) recorded by detailed line survey in the ESF and the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

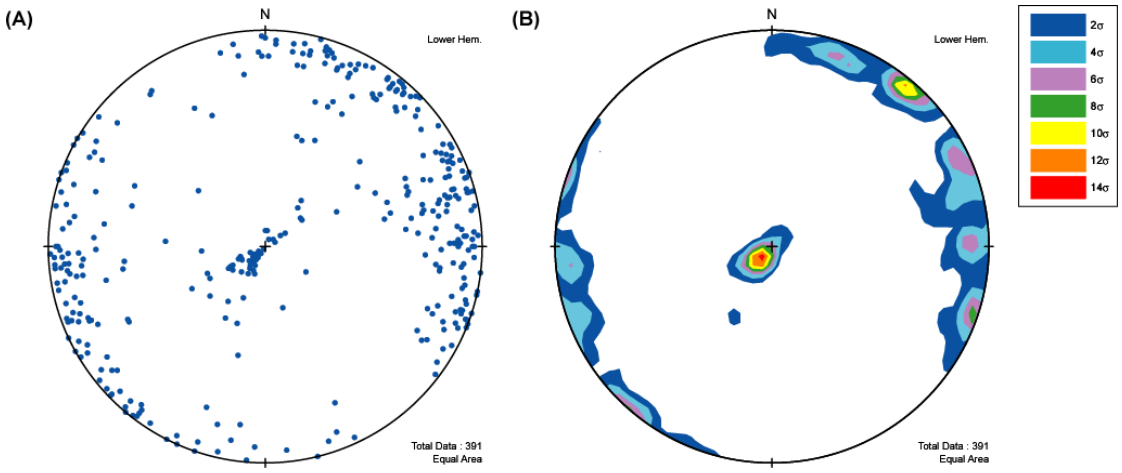

Figure 8. Orientation summary for small-scale fractures from the Topopah Spring Tuff Middle Nonlithophysal zone recorded by detailed line survey in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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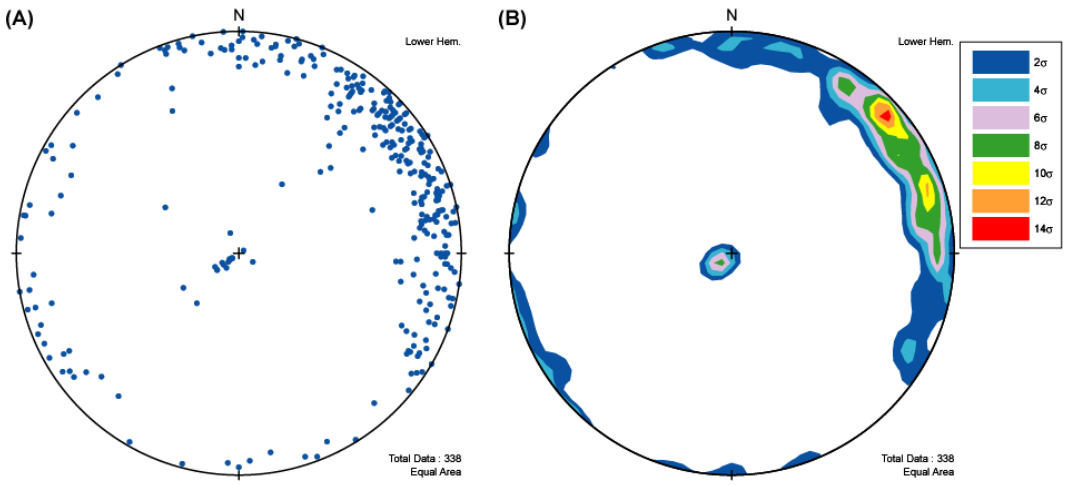

Figure 9. Orientation summary for fractures from the Topopah Spring Tuff Lower Lithophysal zone recorded by detailed line survey in the ESF and the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

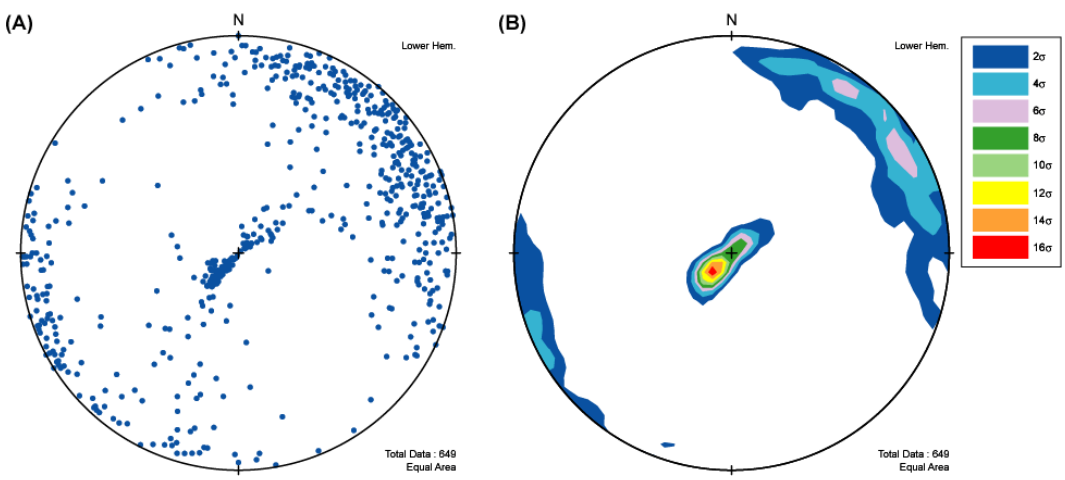

Figure 10. Orientation summary for small-scale fractures from the Topopah Spring Tuff Lower Lithophysal zone recorded by detailed line survey in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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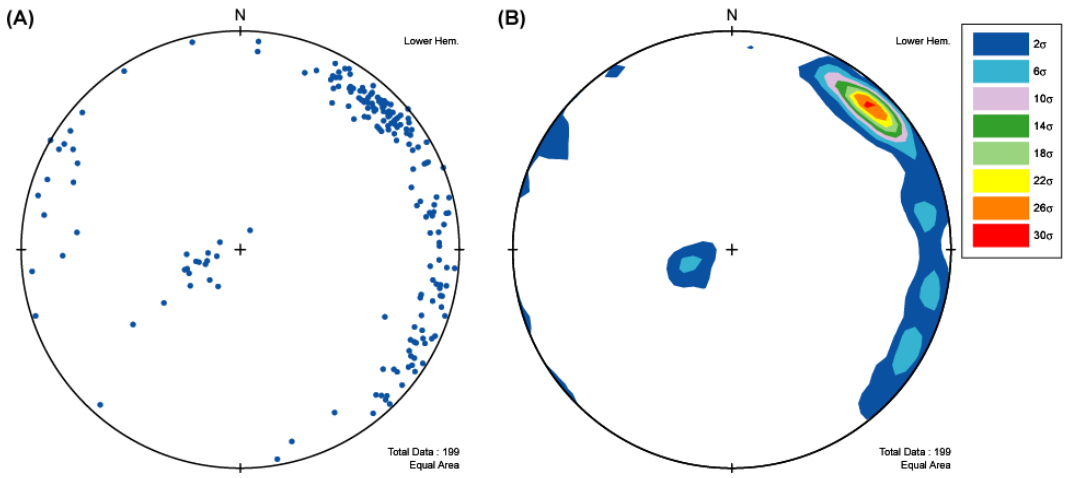

Figure 11. Orientation summary for fractures from the Topopah Spring Tuff Lower Nonlithophysal zone recorded by detailed line survey in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

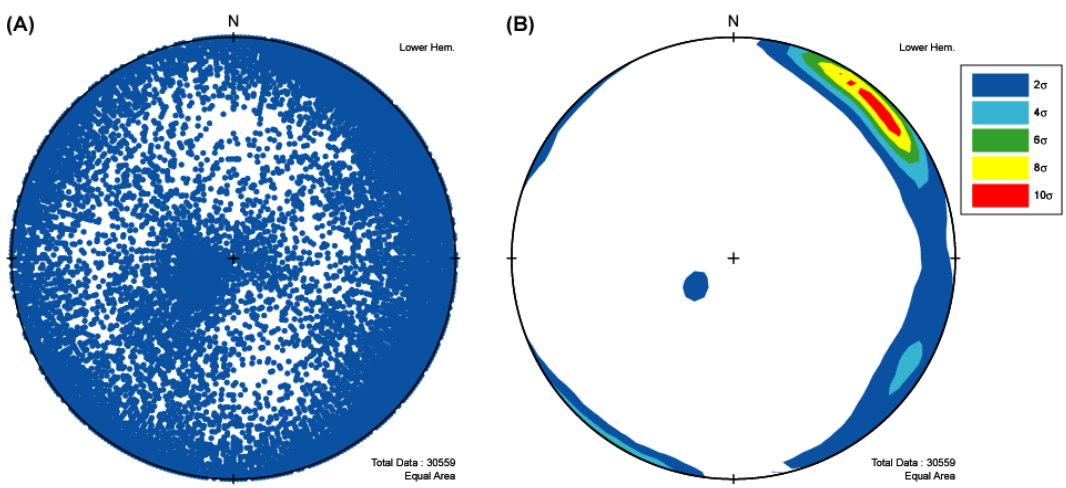

Figure 12. Orientation summary for all fractures recorded by full-periphery geologic mapping in the ESF. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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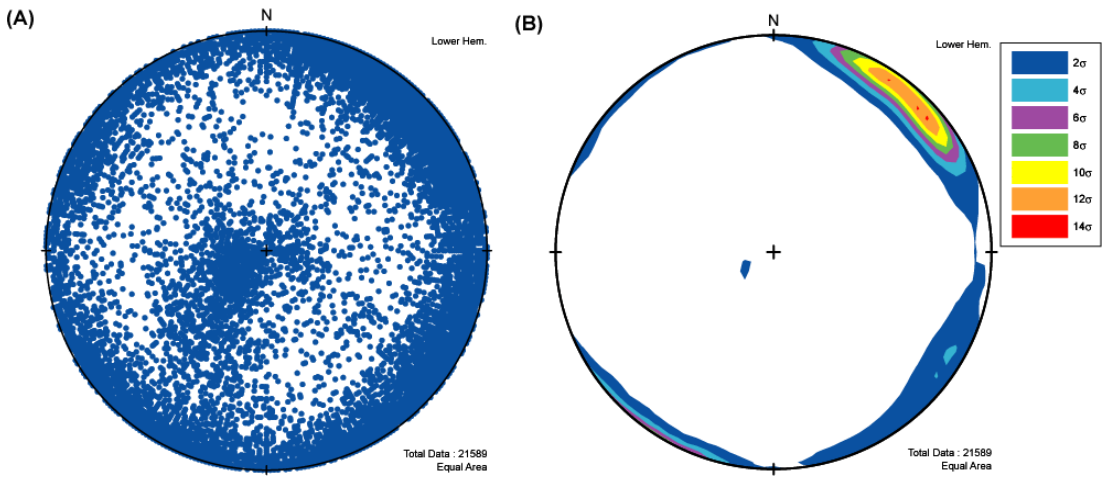

Figure 13. Orientation summary for fractures recorded by full-periphery geologic mapping in the ESF from the Topopah Spring Tuff Upper Lithophysal, Middle Nonlithophysal, and Lower Lithophysal zones. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

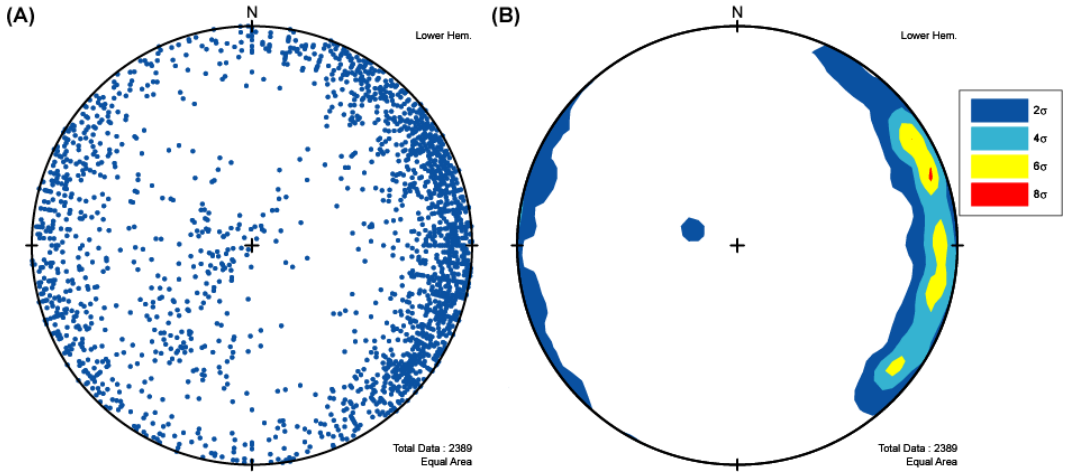

Figure 14. Orientation summary for fractures recorded by full-periphery geologic mapping in the ESF from the Topopah Spring Tuff Upper Lithophysal zone. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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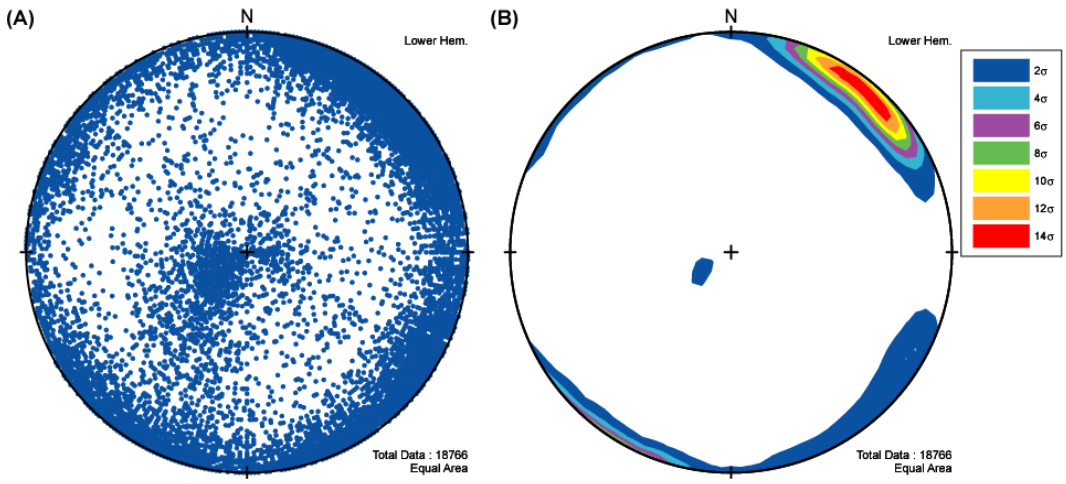

Figure 15. Orientation summary for fractures recorded by full-periphery geologic mapping in the ESF from the Topopah Spring Tuff Middle Nonlithophysal zone. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

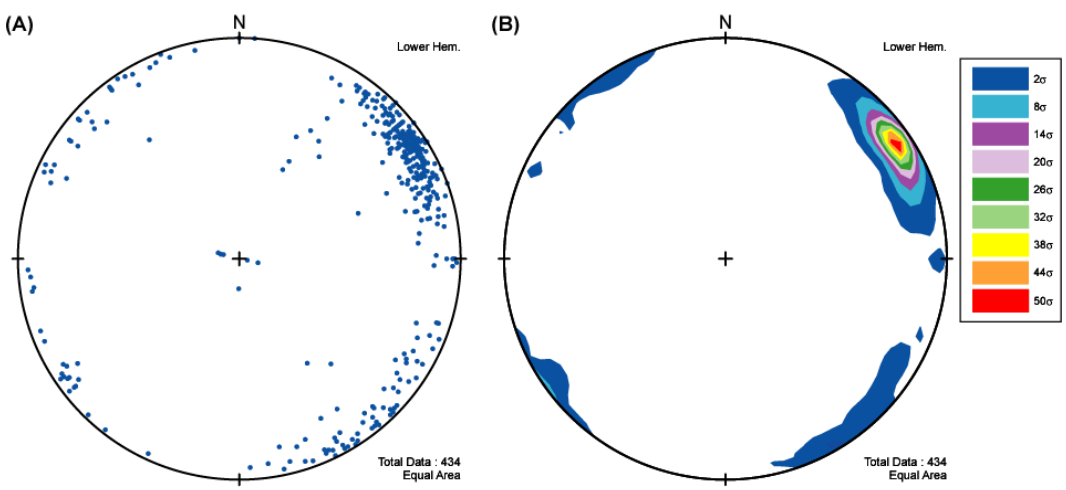

Figure 16. Orientation summary for fractures recorded by full-periphery geologic mapping in the ESF from the Topopah Spring Tuff Lower Lithophysal zone. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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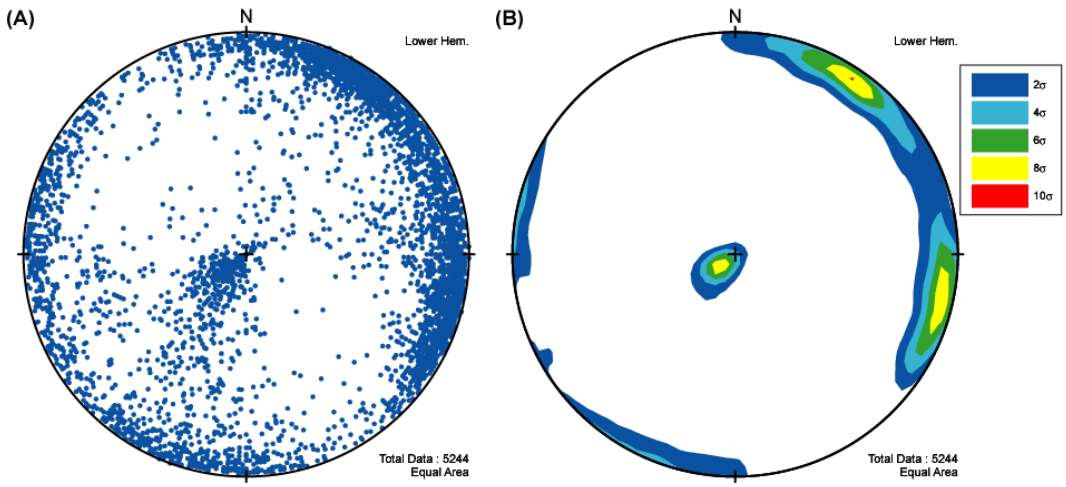

Figure 17. Orientation summary for fractures recorded by full-periphery geologic mapping in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

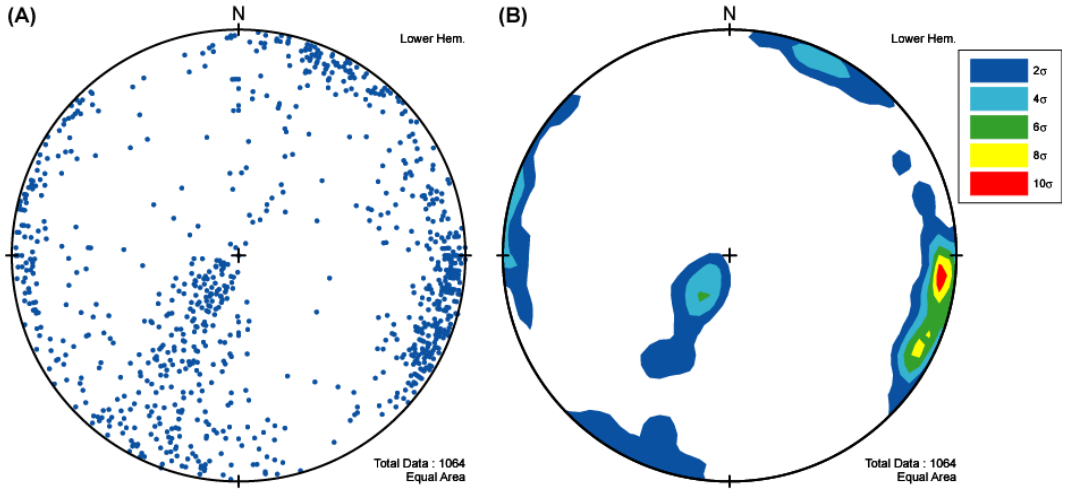

Figure 18. Orientation summary for fractures from the Topopah Spring Tuff Upper Lithophysal zone recorded by full-periphery geologic mapping in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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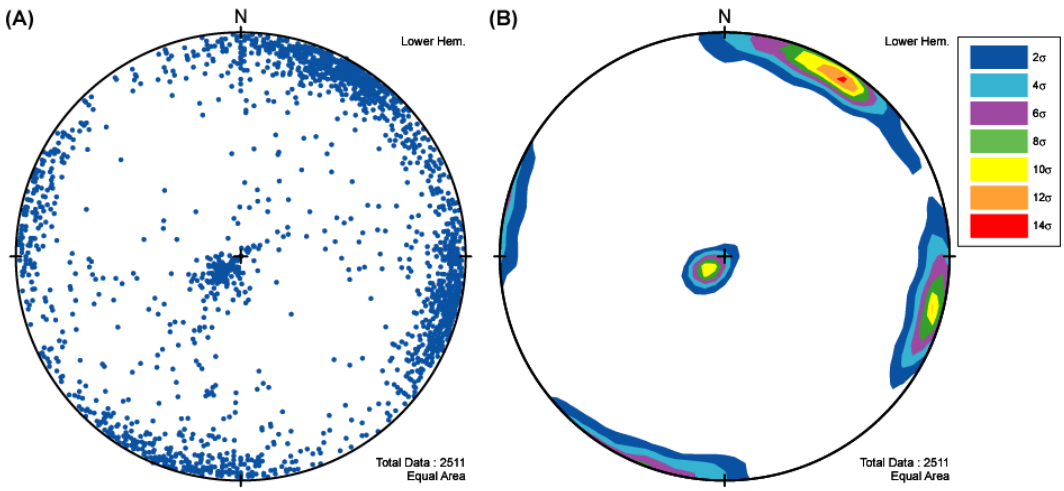

Figure 19. Orientation summary for fractures from the Topopah Spring Tuff Middle Nonlithophysal zone recorded by full-periphery geologic mapping in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

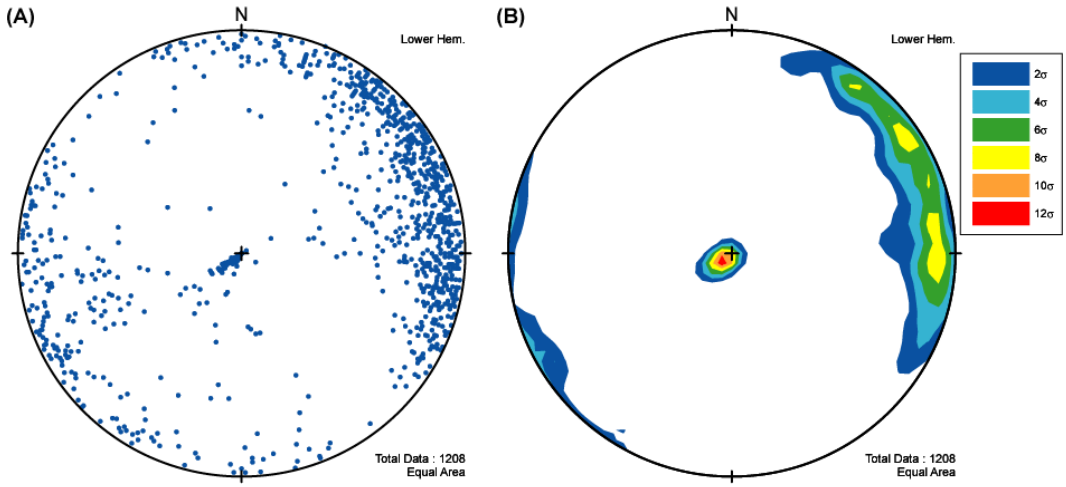

Figure 20. Orientation summary for fractures from the Topopah Spring Tuff Lower Lithophysal zone recorded by full-periphery geologic mapping in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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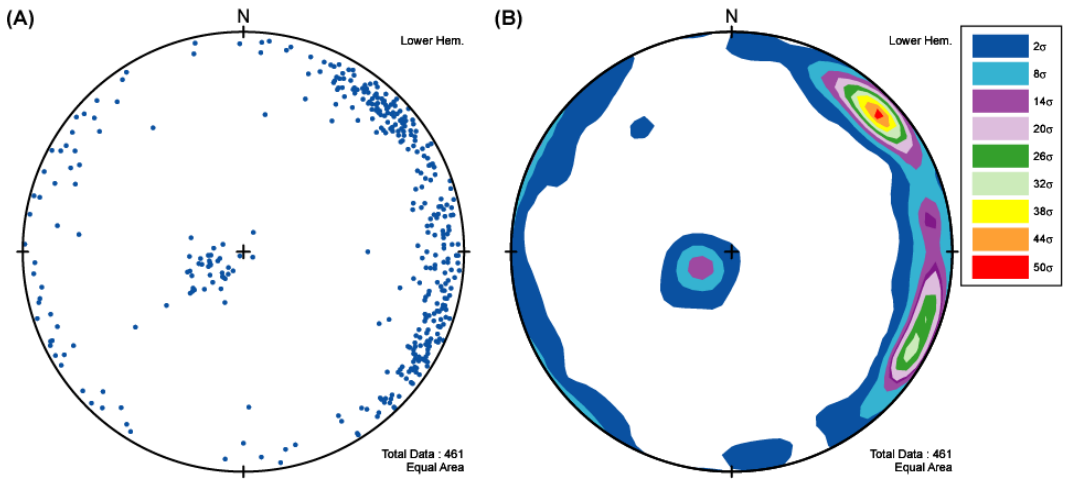

Figure 21. Orientation summary for fractures from the Topopah Spring Tuff Lower Nonlithophysal zone recorded by full-periphery geologic mapping in the ECRB Cross-Drift. (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

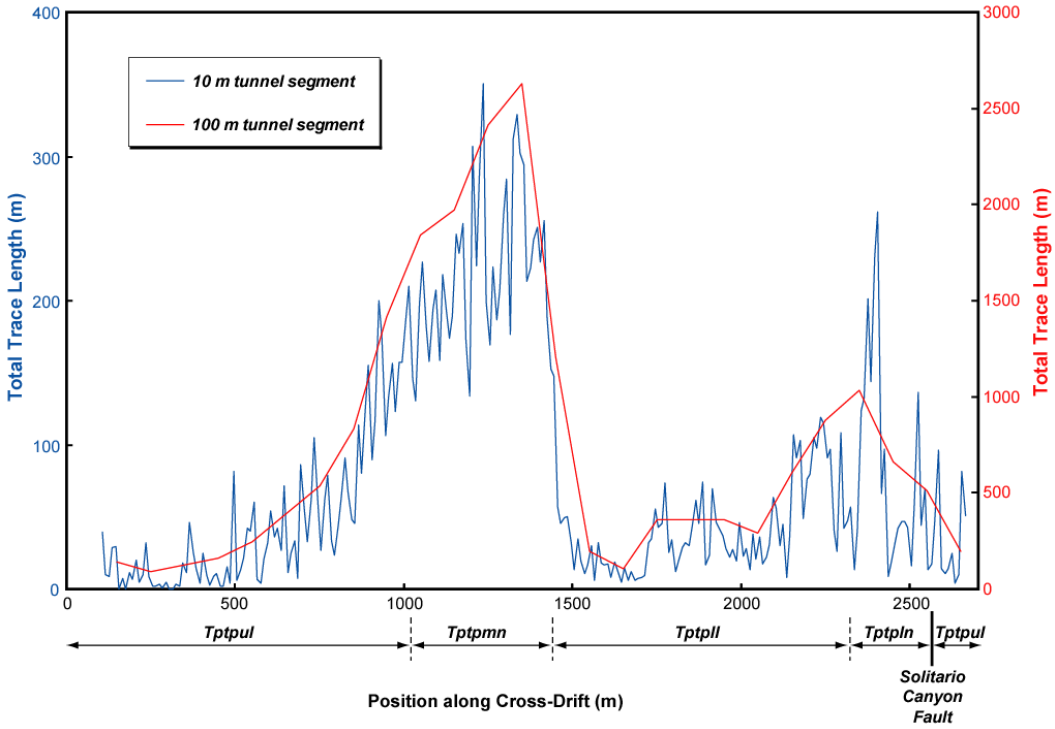

Figure 22. Fracture trace length summary for FPGM data from ECRB Cross-Drift. Total trace length for 10 m [33 ft] and 100 m [328 ft] segments of the ECRB Cross-Drift as determined from full-periphery geologic mapping data. Abbreviations for Topopah Spring Tuff zones: *Tptpul* = Upper Lithophysal; *Tptpmn* = Middle Nonlithophysal; *Tptpll* = Lower Lithophysal; *Tptpln* = Lower Nonlithophysal.

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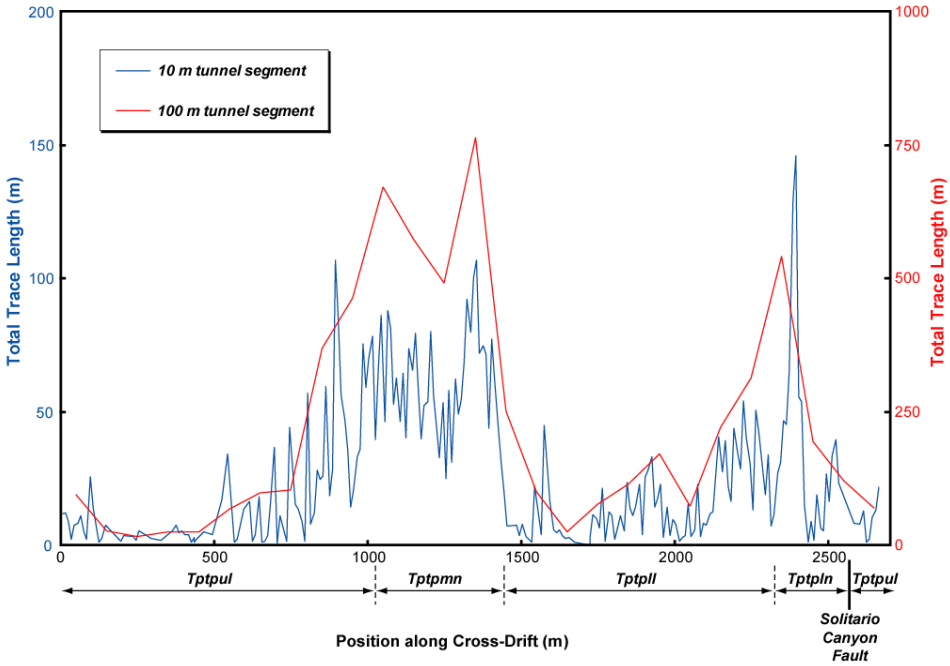

Figure 23. Fracture trace length summary for DLS data from ECRB Cross-Drift. Total trace length for 10 m [33 ft] and 100 m [328 ft] segments of the ECRB Cross-Drift as determined from detailed line survey data. Abbreviations are the same as shown in figure 22.

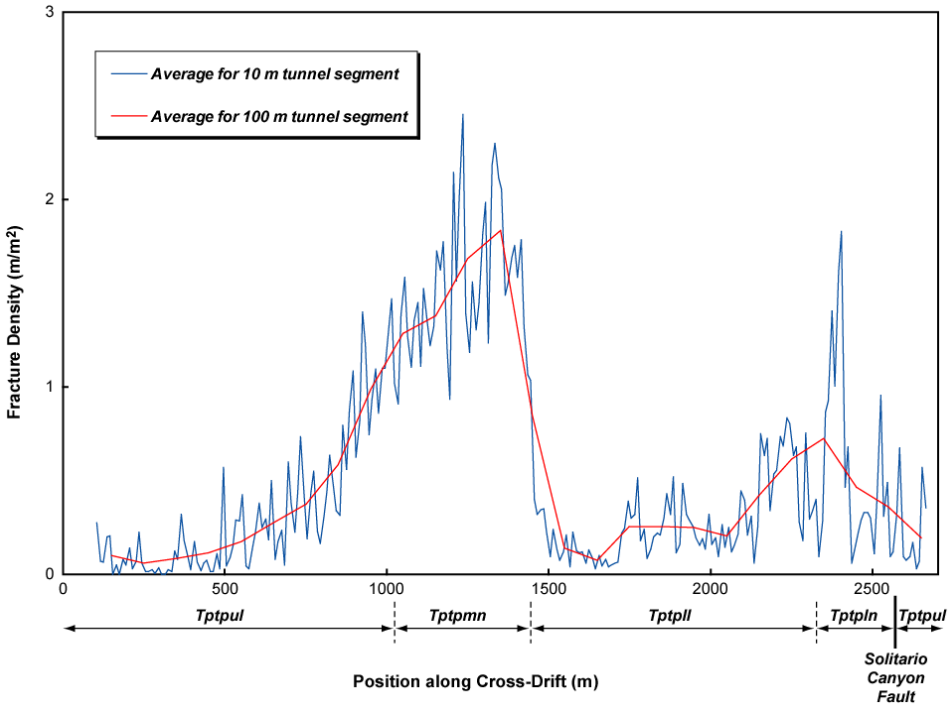

Figure 24. Fracture density summary for FPGM data from ECRB Cross-Drift. Total trace length per unit area (or P_{21}) averaged over 10 m [33 ft] and 100 m [328 ft] segments of the ECRB Cross-Drift as determined from full-periphery geologic mapping data. Abbreviations are the same as shown in figure 22.

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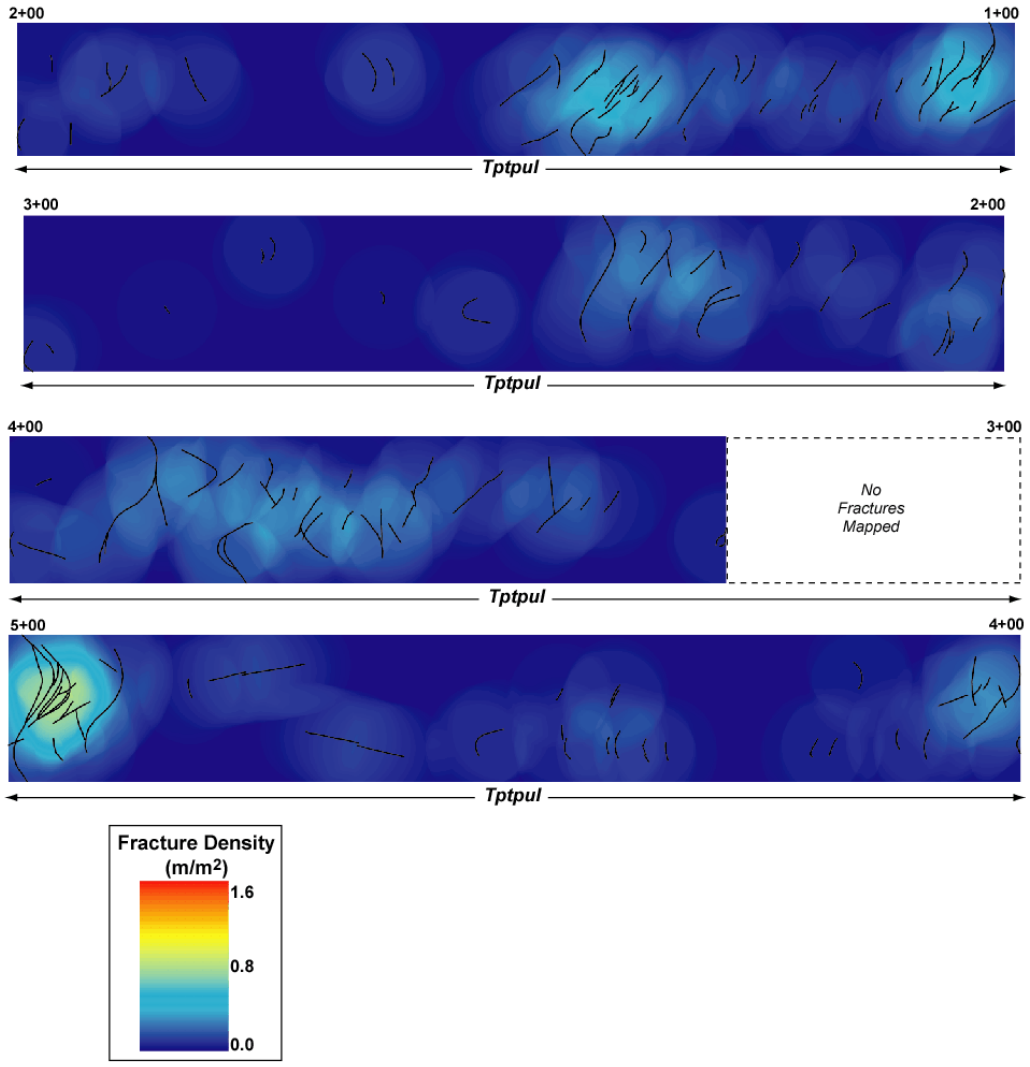

Figure 25. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 1+00 to 5+00. Fracture density is calculated as total trace length per unit area (or P_{21}) within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

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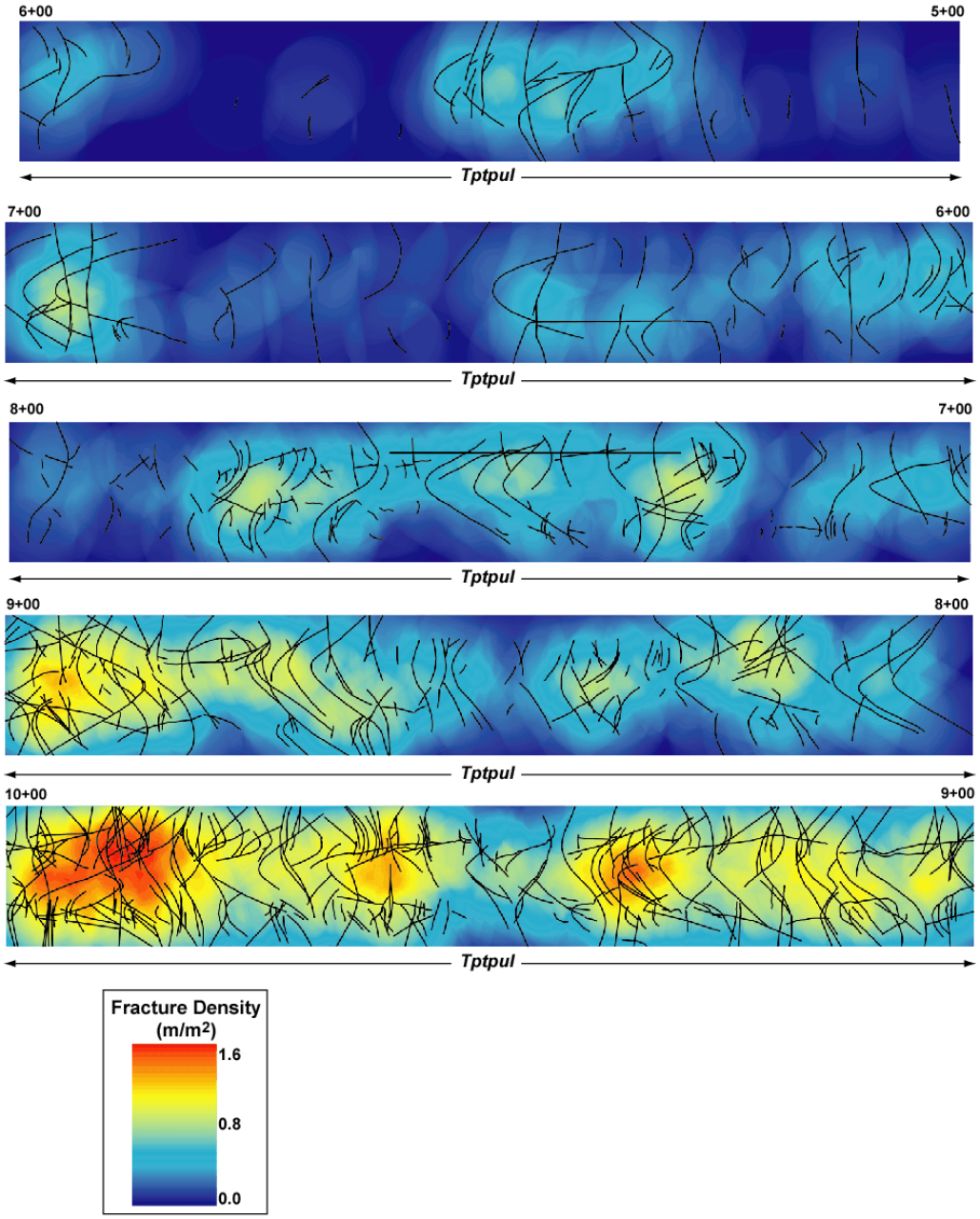

Figure 26. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 5+00 to 10+00. Fracture density is calculated as total trace length per unit area within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

August 19, 2005 KJS

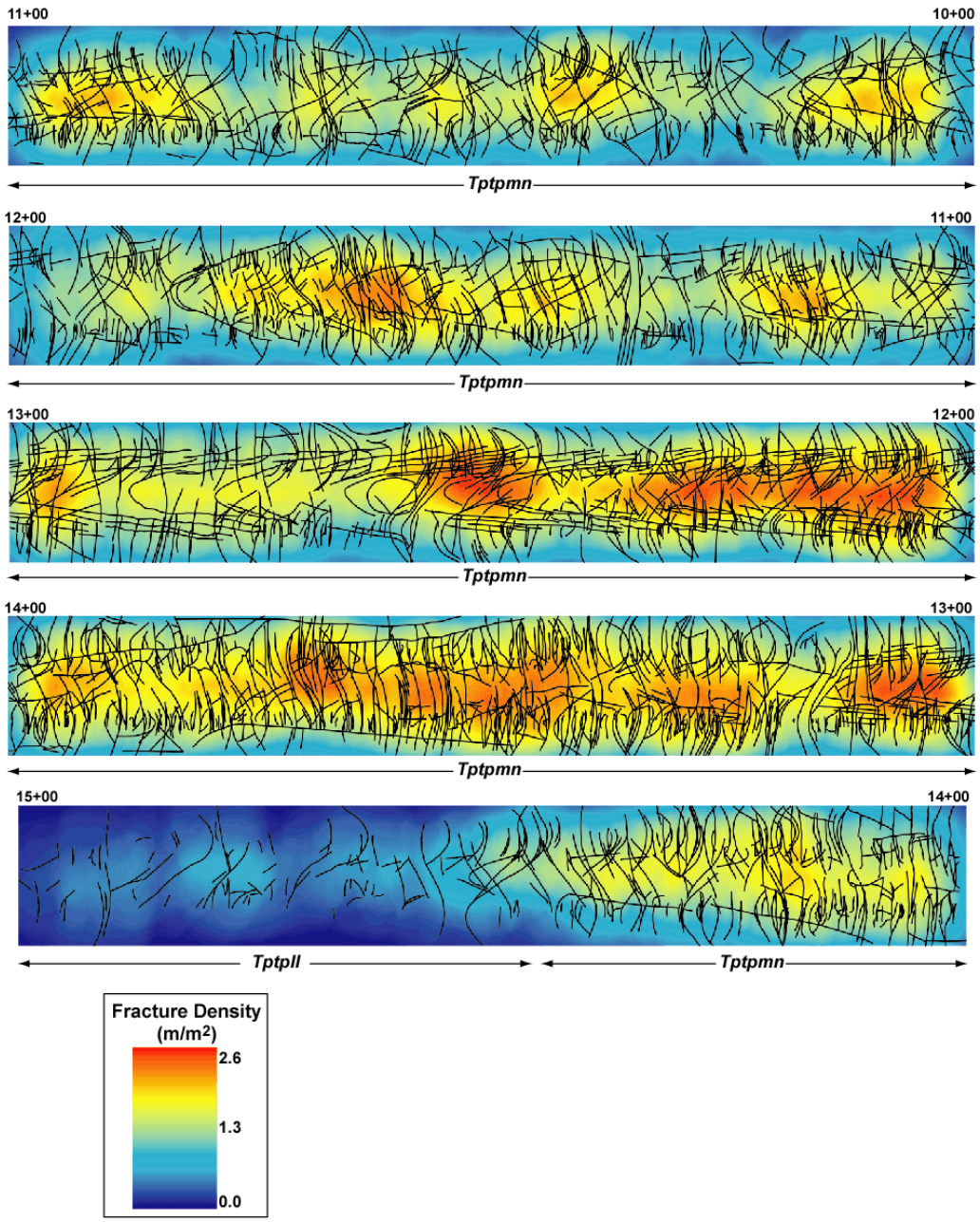

Figure 27. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 10+00 to 15+00. Fracture density is calculated as total trace length per unit area within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

August 19, 2005 KJS

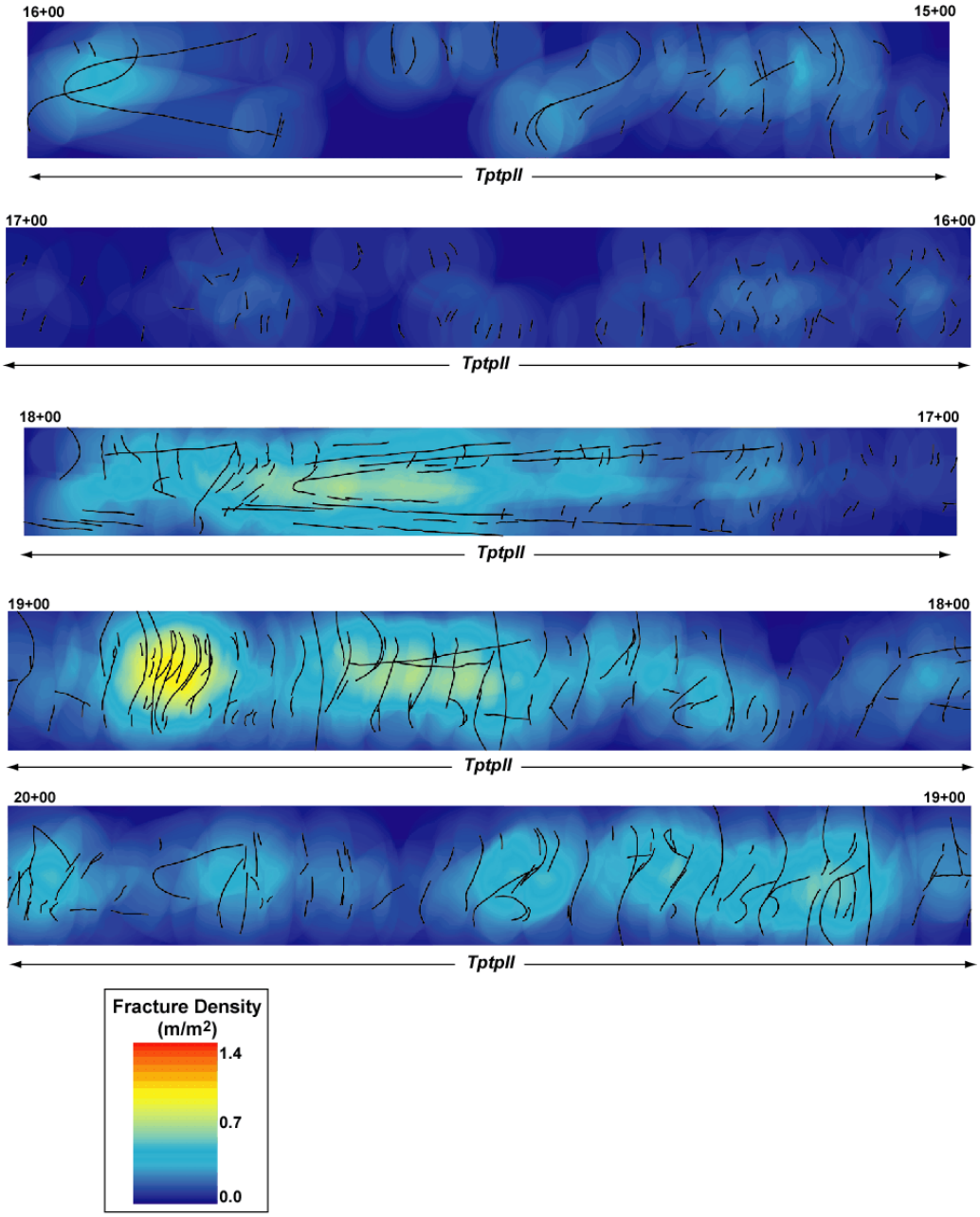

Figure 28. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 15+00 to 20+00. Fracture density is calculated as total trace length per unit area within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

August 19, 2005 KJS

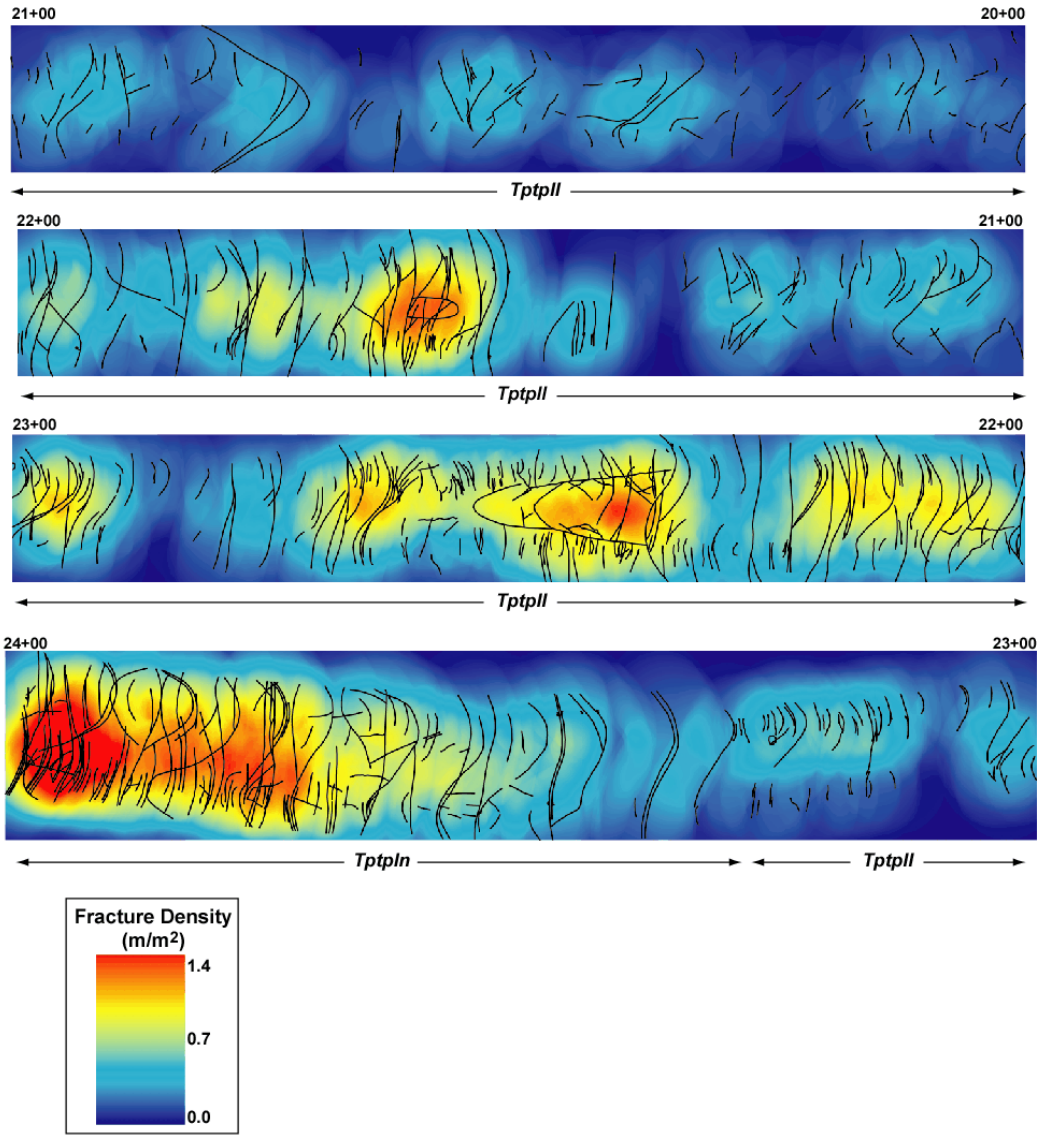

Figure 29. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 20+00 to 24+00. Fracture density is calculated as total trace length per unit area within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

August 19, 2005 KJS

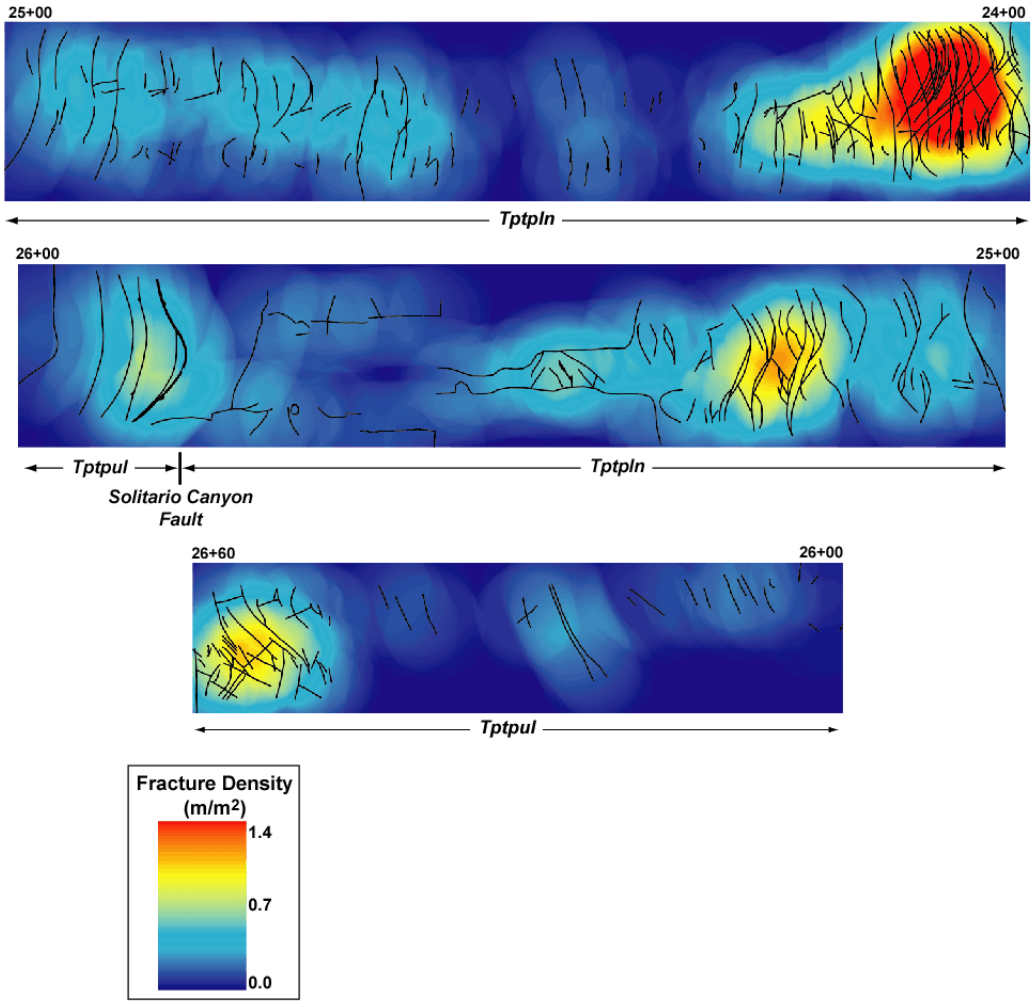

Figure 30. Fracture density contours superimposed over fracture traces from full-periphery geologic mapping in the ECRB Cross-Drift for stations 24+00 to 26+60. Fracture density is calculated as total trace length per unit area within ArcGIS based upon a 5 m [16 ft] diameter search radius. Abbreviations are the same as shown in figure 22.

FracMan/FracWorks

Project Tptpmn Task Drift Degradation Date 03/04 Modeler Lung-Fahy
Seed #: 1 Fracmeter Unit: 50 Truncation mode Region View Center 0,0,0
Direction _____ Scale _____ % displayed 100 Orientation = Pole or Dip Pole # frac sides 6

Frac. Set	Model Type	Generation Region & Dimension	Orientation Trend, Plunge	Dist. Type	K or K1/K2 dispersion	Size Eqv. Radius	Dist. Type	Mean SD	Max. Min.	Elongation	Aspect Ratio	Termin. %	Intensity
S1s	BART	100x100x100	035/06	BiBing	-39.5/-4.5	1.00	TPow (3.5)		8/1	NA	NA	10	0.40
S2s	BART	100x100x100	124/04	BiBing	-11.8/-6.2	1.00	TPow (3.5)		8/1	NA	NA	10	0.30
S3s	BART	100x100x100	209/47	BiBing	-72.6/-8.8	1.00	TPow (3.5)		8/1	NA	NA	10	0.10
VPP	Baecher	100x100x100	237/82	Fisher	05	1.00	Power (3.5)		NA	NA	NA	0	0.16
S1l	BART	100x100x100	035/06	BiBing	-39.5/-4.5	1.00	TPow (3.5)		50/4	NA	NA	15	0.2
S2l	BART	100x100x100	124/04	BiBing	-11.8/-6.2	1.00	TPow (3.5)		50/4	NA	NA	15	0.2
S3l	BART	100x100x100	209/47	BiBing	-72.6/-8.8	1.00	TPow (3.5)		50/4	NA	NA	15	0.15

NN factor ____ NN export: ____ WZ inten: ____ WZ parall: ____ WZ large: ____ WZ close ____ Frac Dim (LL,FB)(.5-5.) ____
Zone Thick ____ Fracs ____ # iterations ____ Frac Dim (POCS) ____ Ampl Shaper Fac (POCS) ____ Box Frac Dim ____ Spherical/ Exp ____
Variogram ____ Semivariogram Sill ____ Corr Length ____

____.FDT (Binary. Cannot port to non DOS computers. Cannot be edited in standard word processing.)
____.BAB (Babylonian ASCII version of FDT. Only fracture data stored. Can be ported to non DOS computers. No standard word processing.)
____.DCM (Standard ASCII version of FDT. Only fracture data stored. Can be ported to most computers. Can be edited by standard word processing. Large files.)
____.SAM (ASCII) ____ .ORS (ASCII) ____.PCS (ASCII, for conditioned data)
____.F2D (ASCII, fracture trace data)

NOTE: See Figure 6-17 for detailed line survey source DTNs. The parameter, "K or K1/K2 dispersion" is determined using CLUSTRAN (with the exception of VPP, or vapor-phase parting, which is determined visually by comparing simulated stereonets to observed stereonets). The parameter, "Size Eqv. Radius" is the mean radius (m). The power law distribution is used for the parameter, "Dist. Type." The power law is selected because the fracture process generally follows power law physics, such that the number of fractures greater than a given length (x) is proportional to 1/x raised to the power law exponent. The parameter, "Intensity" is selected to maintain the proportion of fractures in each set.

Figure 6-18. FracMan Input Sheet for the Tptpmn

Figure 31. Summary of FracMan input values for the Topopah Spring Tuff Middle Nonlithophysal zone from BSC (2004b).

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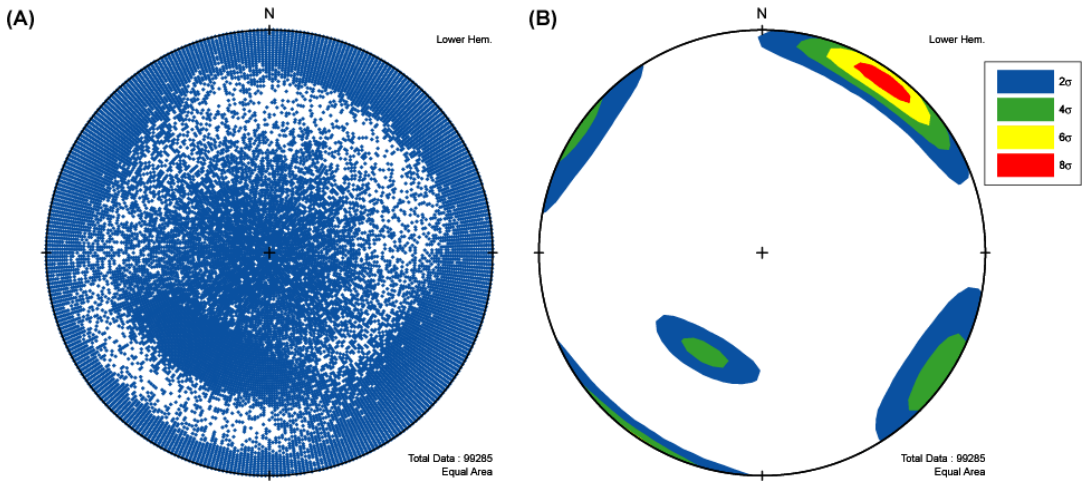

Figure 32. Orientation summary for synthetic fractures generated for the Topopah Spring Tuff Middle Nonlithophysal zone (test 1). (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

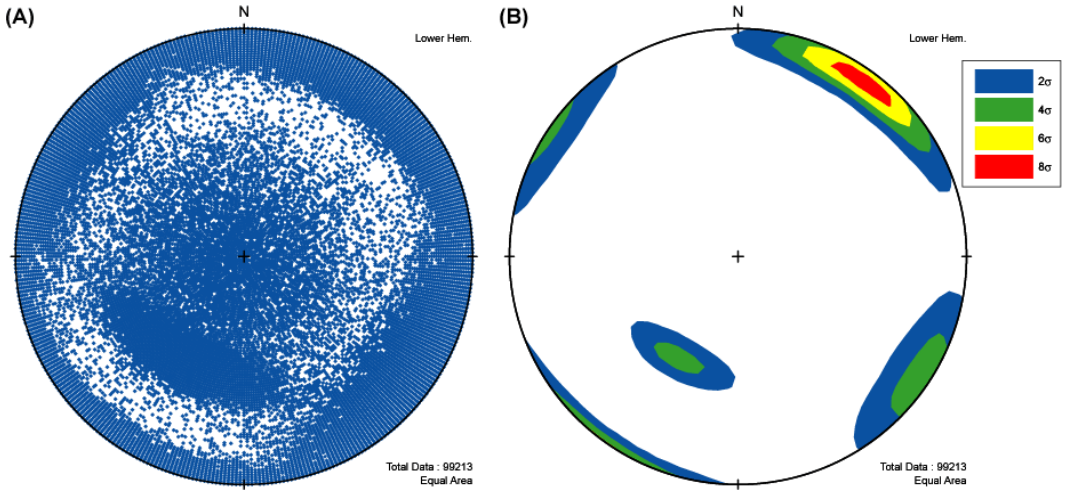

Figure 33. Orientation summary for synthetic fractures generated for the Topopah Spring Tuff Middle Nonlithophysal zone (test 2). (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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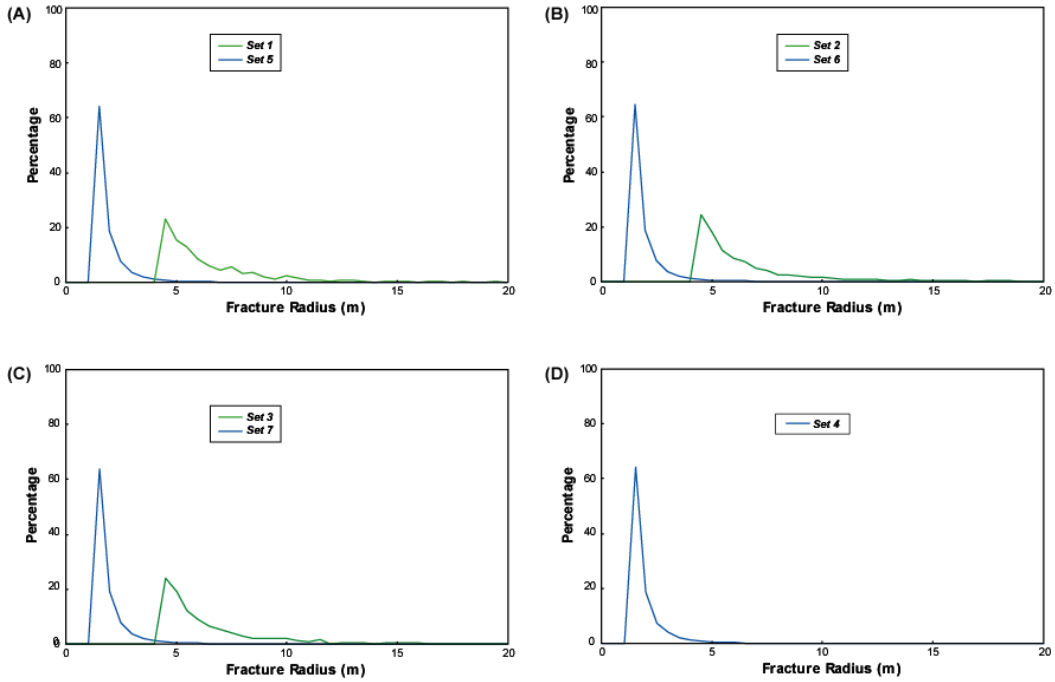

Figure 34. Summary of synthetic fracture radius distributions for the Topopah Spring Tuff Middle Nonlithophysal zone (test 1). (A) Set 1and 5 fractures are northwest-striking and subvertical. (B) Set 2 and 6 fractures are northeast-striking and subvertical. (C) Set 3 and 7 fractures are northwest-striking with an intermediate dip to the northeast. (D) Set 4 fractures are subhorizontal.

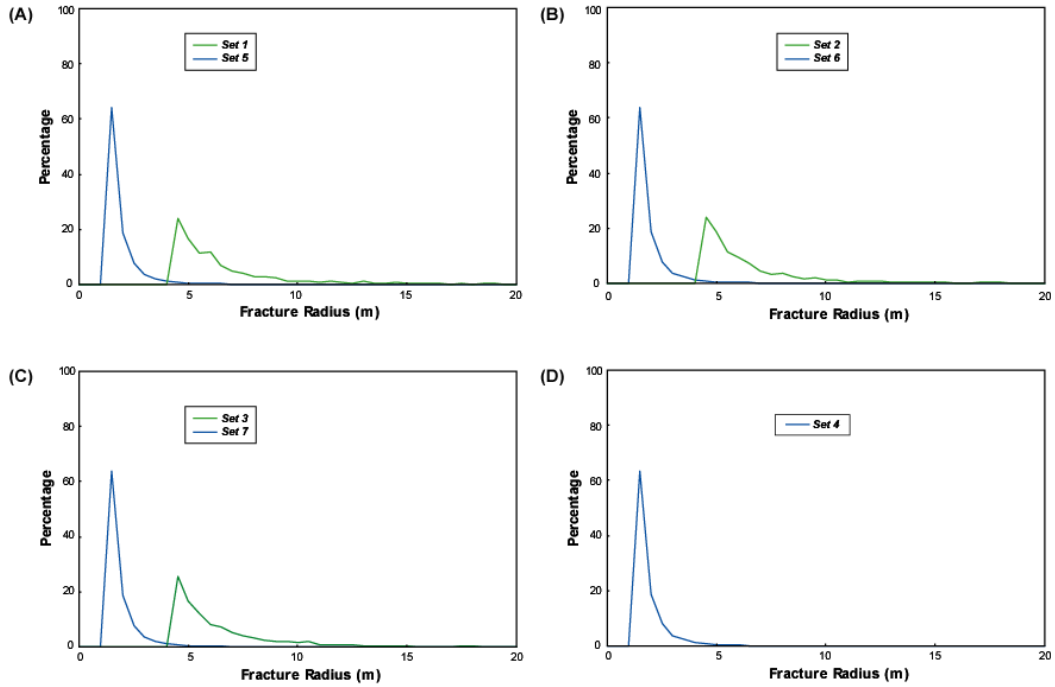

Figure 35. Summary of synthetic fracture radius distributions for the Topopah Spring Tuff Middle Nonlithophysal zone (test 2). (A) Set 1 and 5 fractures are northwest-striking and subvertical. (B) Set 2 and 6 fractures are northeast-striking and subvertical. (C) Set 3 and 7 fractures are northwest-striking with an intermediate dip to the northeast. (D) Set 4 fractures are subhorizontal.

Project Tptpll Task Drift Degradation Date 01-24-03 Modeler Lung-Fahy
Seed #: 0725 Fracmeter Unit: 50 Truncation mode Region View Center 0,0,0
Direction _____ Scale _____ % displayed 100 Orientation = Pole or Dip Pole # frac sides 6

Frac Set	Model Type	Generation Region & Dimension	Orientation TR,Pl	Dist. Type	k dispersion	Size eqv. Radius	Dist. type	Mean SD	Max. Min.	Elongation	Aspect Ratio	Termin %	Intensity
1	Baecher	100x100x100	239/76	Fisher	70	1.30	Power (3.1)			NA	NA	5	0.02
2	Baecher	100x100x100	040/10	Fisher	70	1.80	Power (3.1)			NA	NA	10	0.05
3	Baecher	100x100x100	085/10	Fisher	70	1.53	Power (3.1)			NA	NA	10	0.02
4	Baecher	100x100x100	040/10	Fisher	100	0.60	Power (3.1)			NA	NA	70	0.035
5	Baecher	100x100x100	085/10	Fisher	100	0.60	Power (3.1)			NA	NA	70	0.007
6	Baecher	100x100x100	008/05	Fisher	100	0.60	Power (3.1)			NA	NA	70	0.002

NN factor _____ NN export: _____ WZ inten: _____ WZ parall: _____ WZ large: _____ WZ close _____ Frac Dim (LL,FB)(.5-5.) _____
Zone Thick _____ Fracs _____ # iterations _____ Frac Dim (POCS) _____ Ampl Shaper Fac (POCS) _____ Box Frac Dim _____ Spherical/ Exp _____
Variogram _____ Semivariogram Sill _____ Corr Length _____

_____.FDT (binary, cant port to non DOS computers, cannot be edited in std word processing)
_____.BAB (babylonian ASCII version of FDT, only frac. data stored. Can be ported to non DOC computers. No std word processing.)
_____.DCM (Std ASCII version of FDT. Only frac data stored. Can be ported to most computers. Can be edited by std. Word processing. Large files)
_____.SAM (ASCII) _____.ORS (ASCII) _____.PCS (ASCII, for conditioned data)
_____.F2D (ASCII, frac trace data)

Source: DTN: GS990408314224.001 [DIRS 108396]; GS990408314224.002 [DIRS 105625].

NOTE: The parameter, "k dispersion" is determined visually by comparing simulated stereonets to observed stereonets. The parameter, "size eqv. radius" is the mean radius (m). The power law distribution is used for the parameter, "dist. type." The power law is selected because the fracture process generally follows power law physics, such that the number of fractures greater than a given length (x) is proportional to 1/x raised to the power law exponent. The parameter, "intensity" is selected to maintain the proportion of fractures in each set.

Figure B-3. FracMan Input Sheet for the Tptpll

Figure 36. Summary of FracMan input values for the Topopah Spring Tuff Lower Lithophysal zone from BSC (2004b).

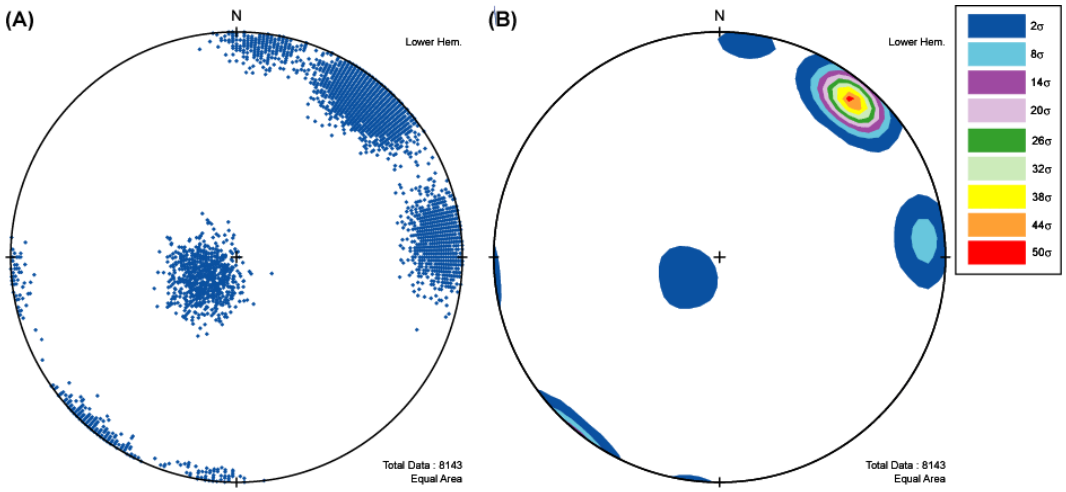

Figure 37. Orientation summary for synthetic fractures generated for the Topopah Spring Tuff Lower Lithophysal zone (test 1). (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

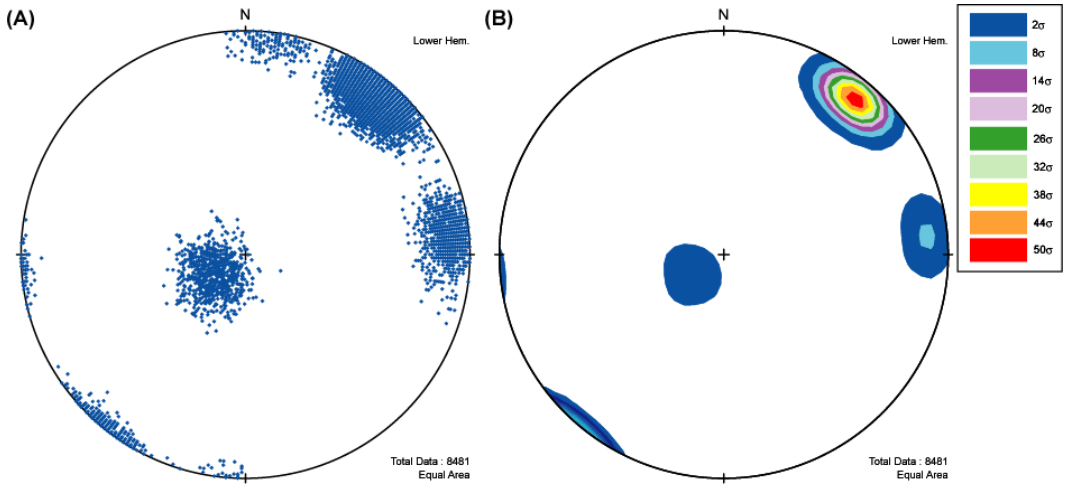

Figure 38. Orientation summary for synthetic fractures generated for the Topopah Spring Tuff Lower Lithophysal zone (test 2). (A) Equal-area stereonet plot of poles to fracture planes. (B) Contours of poles to fracture planes calculated with 1% area method.

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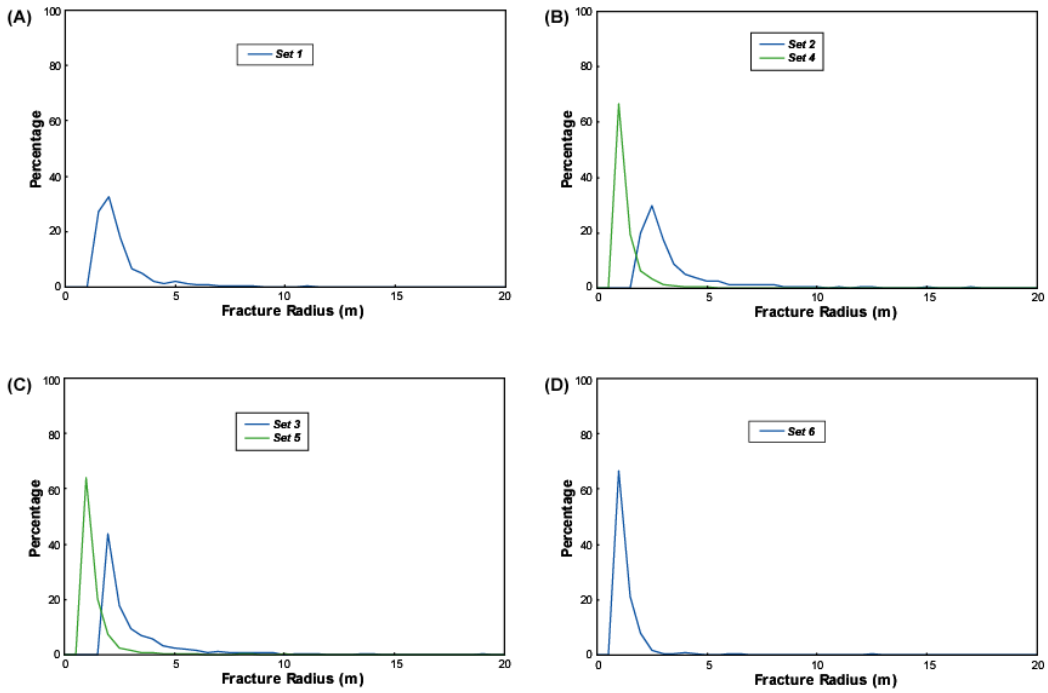

Figure 39. Summary of synthetic fracture radius distributions for the Topopah Spring Tuff Lower Lithophysal zone (test 1). (A) Set 1 fractures are subhorizontal. (B) Set 2 and 4 fractures are northwest-striking and steeply southwest dipping. (C) Set 3 and 5 fractures are north-south-striking and steeply west dipping. (D) Set 6 fractures are east-west-striking and steeply south dipping.

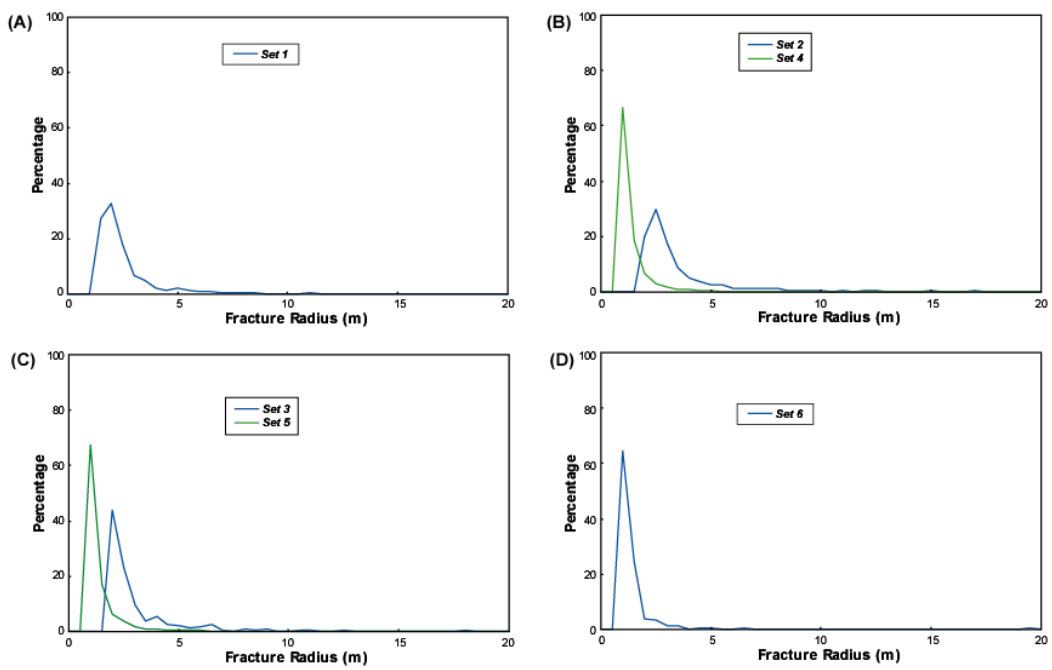

Figure 40. Summary of synthetic fracture radius distributions for the Topopah Spring Tuff Lower Lithophysal zone (test 2). (A) Set 1 fractures are subhorizontal. (B) Set 2 and 4 fractures are northwest-striking and steeply southwest dipping. (C) Set 3 and 5 fractures are north-south-striking and steeply west dipping. (D) Set 6 fractures are east-west-striking and steeply south dipping.

August 19, 2005 KJS

DOCUMENTS CITED

BSC (Bechtel SAIC Company). "Drift Degradation Analysis." ANL-EBS-MD-000027 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. 2004b.

Kamb, W.B. "Petrofabric observations from Blue Glacier, Washington, in relation to theory and experiment." Journal of Geophysical Research 64, 1891-1909. 1959.

Knopf, E.B. and E. Ingerson. "Structural Petrology." Geological Society of America Memoir 6. 1938.

Turner, F.J. and L.E. Weiss. "Structural Analysis of Metamorphic Tectonites." New York, New York: McGraw-Hill Book Company, Inc. 1963.

September 1, 2005 KJS

Summary data table from "DLS_Tptpul.XLS":

DLS data Tptpul from the ECRB and ESF using a lower tracelength cut-off of 1 meter:

		Count	Dip (deg)	Traclength above (m)	Traclength below (m)	Total Tracelength (m)	Displacement (m)	Displacement (cm)	Truncated Terzaghi True Spacing (m)	Truncated Terzaghi Linear Fracture Intensity (m^{-1})
All	Mean =	1758	76.05	1.62	0.94	2.56	2.95	294.55		
	Median =		81.00	0.62	0.68	**1.42**	**0.10**	**10.00**		
	Std. Dev. =		14.49	3.12	0.91	3.59	20.77	2076.64		
	Skew =		-2.19	4.21	1.54	3.87	8.36	8.36		
Set 1	Mean =	538	80.56	1.19	0.90	2.09	1.08	107.85	2.82	
	Median =		83.00	0.61	0.66	**1.44**	**0.08**	**8.00**	**0.75**	**1.34**
	Std. Dev. =		7.26	1.80	0.84	2.17	2.75	275.07	8.80	25.13
	Skew =		-0.98	4.07	1.25	3.56	3.68	3.68	8.48	
Set 2	Mean =	1024	80.05	1.43	0.85	2.29	4.76	475.54	1.73	
	Median =		82.00	0.55	0.62	**1.30**	**0.14**	**14.00**	**0.65**	**1.53**
	Std. Dev. =		6.90	2.85	0.79	3.25	27.98	2798.18	3.55	24.53
	Skew =		-0.68	4.29	1.42	4.00	6.24	6.24	6.00	
Set 3 (Sub-H)	Mean =	95	30.22	3.98	1.76	5.73	0.20	19.60	3.98	
	Median =		34.00	2.15	1.63	**4.31**	**0.11**	**11.00**	**1.29**	**0.77**
	Std. Dev. =		11.89	5.51	1.53	6.18	0.18	18.47	6.59	20.80
	Skew =		-0.63	2.34	0.89	2.12	1.51	1.51	3.46	
Set 4 (Random)	Mean =	101	53.41	3.62	1.25	4.87	0.16	16.00		
	Median =		54.00	1.13	1.10	2.10	0.10	10.00		
	Std. Dev. =		4.07	5.72	1.08	6.42	0.16	15.72		
	Skew =		-0.39	2.28	0.81	2.15	2.20	2.20		
	Total =	1758								

Summary data table from "DLS_Tptpmn_All.XLS":

DLS data for Tptpmn in the ECRB and ESF using a lower tracelength cut-off of 1 meter (includes data from the Intensely Fractured Zone):

		Count	Dip (deg)	Traclength above (m)	Traclength below (m)	Total Tracelength (m)	Displacement (m)	Displacement (cm)	Truncated Terzaghi True Spacing (m)	Truncated Terzaghi Linear Fracture Intensity (m^{-1})
All	Mean =	13493	77.67	1.14	0.98	2.12	0.28	27.99		
	Median =		**83.00**	**0.70**	**0.75**	**1.58**	**0.04**	**4.00**		
	Std. Dev. =		16.77	1.89	1.00	2.26	2.64	264.22		
	Skew =		-2.85	9.87	8.50	7.63	18.01	18.01		
Set 1	Mean =	8919	82.91	1.15	1.03	2.18	0.10	10.00	0.42	
	Median =		**84.00**	**0.77**	**0.84**	**1.70**	**0.04**	**4.00**	**0.19**	**5.20**
	Std. Dev. =		4.65	1.64	0.88	1.96	0.26	26.33	4.01	35.12
	Skew =		-0.63	7.91	1.26	5.44	6.13	6.13	77.99	
Set 2	Mean =	2973	82.82	1.08	0.82	1.90	0.18	17.60	0.92	
	Median =		**84.00**	**0.60**	**0.60**	**1.35**	**0.04**	**4.00**	**0.46**	**2.19**
	Std. Dev. =		5.05	2.32	0.79	2.62	0.86	86.46	1.50	23.62
	Skew =		-0.62	13.13	1.54	10.81	7.96	7.96	6.07	
Set 3 (Sub-H)	Mean =	679	15.95	1.34	1.14	2.47	0.13	13.40	1.19	
	Median =		**17.00**	**0.70**	**0.50**	**1.54**	**0.05**	**5.00**	**0.52**	**1.92**
	Std. Dev. =		7.56	2.19	2.40	3.40	0.31	30.50	2.23	33.88
	Skew =		-0.06	3.89	11.09	6.22	4.15	4.15	6.49	
Set 4 (Random)	Mean =	922	55.55	1.11	0.91	2.02	1.90	190.16		
	Median =		**60.00**	**0.52**	**0.56**	**1.27**	**0.06**	**6.00**		
	Std. Dev. =		11.78	2.24	0.96	2.65	8.83	882.65		
	Skew =		-0.65	6.38	1.38	5.08	5.56	5.56		
	Total =	**13493**								

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Summary data table from "DLS_Tptpmn_IFZ-only.XLS":

DLS data for only the Intensely Fractured Zone (Stations 42+00 to 51+50) in the ESF using a lower tracelength cut-off of 1 meter:											
										Truncated Terzaghi	
		Count		DIP (degrees)	Tracelength above (m)	Tracelength below (m)	Total Tracelength (m)	Displacement (m)	Displacement (cm)	True Spacing (m)	Linear Fracture Intensity (m^{-1})
All	Mean =	4566		81.78	1.11	1.07	2.18	0.04	4.38		
	Median			84.00	0.84	0.95	**1.80**	**0.03**	**3.00**		
	Std. Dev. =			9.21	1.33	0.83	1.59	0.04	4.22		
	Skew =			-4.77	5.36	0.86	4.13	2.83	2.83		
Set 1	Mean =	3875		83.10	1.13	1.10	2.23	0.04	4.39	0.20	
	Median			84.00	0.87	0.98	**1.85**	**0.03**	**3.25**	**0.12**	**8.27**
	Std. Dev. =			4.33	1.34	0.83	1.60	0.04	3.57	0.25	38.56
	Skew =			-0.66	5.64	0.81	4.40	1.86	1.86	5.89	
Set 2	Mean =	525		83.23	1.09	0.95	2.04	0.04	4.41	1.34	
	Median			84.00	0.75	0.85	**1.57**	**0.03**	**3.00**	**0.74**	**1.35**
	Std. Dev. =			4.95	1.34	0.78	1.63	0.05	4.97	1.77	19.06
	Skew =			-0.70	3.40	1.01	2.75	3.15	3.15	2.82	
Set 3 (Sub-H)	Mean =	54		17.76	0.62	0.59	1.21			2.08	
	Median			18.00	0.33	0.39	**0.96**			**0.43**	**2.32**
	Std. Dev. =			6.87	0.89	0.73	1.10			5.19	14.27
	Skew =			-0.38	2.31	1.81	2.74			4.16	
Set 4 (Random)	Mean =	112		59.20	0.79	0.94	1.73	0.03	3.00		
	Median			65.00	0.51	0.58	**1.37**	**0.03**	**3.00**		
	Std. Dev. =			11.62	0.84	0.99	1.26				
	Skew =			-1.23	1.43	1.57	1.33				

July 6, 2006 KJS

ANALYSIS OF SUBSURFACE FAULT AND FRACTURE DATA FROM THE PTn

Introduction

The following notebook entries document work done to support Chapter 3.2 of "The Nature of Flow in the Faulted and Fractured Paintbrush Nonwelded Hydrogeologic Unit" (Intermediate Milestone 06002.01.262.640). The only software used in these analyses are the QA-controlled commercial-off-the-shelf programs Adobe® Illustrator® Version CS2 (Adobe Systems, Inc., 2005), Microsoft® Excel 2002 (Microsoft Corporation, Inc., 2002), and RockWare StereoStat® Version 1.3 (Rockware, Inc., 2004).

Analyses are based on a subset of the detailed line survey (DLS) data collected from the Exploratory Studies Facility (ESF) (i.e., Barr, et al., 1996; Eatman, et al., 1997) that are compiled in the Excel spreadsheet `ESF_DLS_PTn.xls`. Analyses also use a subset of the fracture data collected via full-periphery geologic mapping (FPGM) conducted in the ESF (compiled in the Excel spreadsheet `ESF_FPGM_PTn.xls`.)

The basic analysis procedure is similar to that employed by Smart, et al., (2006), including in some instances the application of correction to account for the bias introduced by the ESF orientation (Terzaghi, 1965). The first step is extraction of fault and fracture data for only the PTn interval from the spreadsheet containing all DLS data for ESF. The DLS data was collected by station location and the corresponding lithostratigraphic interval. For the purposes of the report, this analysis employs a six part subdivision of the Paintbrush Tuff nonwelded hydrogeologic unit (Table 3.2-1) that generally corresponds to the unsaturated zone flow model layers as defined in Bechtel SAIC Company, LLC. (2004).

Table 3.2-1. Comparison Of Lithostratigraphy And Unsaturated Zone Flow Model Layers For the Paintbrush Nonwelded Hydrogeologic Unit As Used In This Report. Table Modified From Bechtel SAIC Company, LLC. (2004, Table 2-1).

Lithostratigraphic Unit	Unsaturated Zone Flow Model Layer
Tiva Canyon Tuff, Crystal-Poor Member, Vitric Zone, Nonwelded Subzone (Tpcpv1)	PTn21
Pre-Tiva Canyon Bedded Tuff (Tpbt4)	PTn22
Yucca Mountain Tuff (Tpy)	PTn23
Pre-Yucca Mountain Bedded Tuff (Tpbt3)	PTn24
Pah Canyon Tuff (Tpp)	PTn25
Pre-Pah Canyon Bedded Tuff (Tpbt2); Topopah Spring Tuff, crystal-rich member, vitric zone, non- to partially welded subzone (Tptrv3); Topopah Spring Tuff, crystal-rich member, vitric zone, moderately welded subzone (Tptrv2)	PTn26

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The exact breakdown of subdivisions as defined in Bechtel SAIC Company, LLC. (2004) places portions of the Yucca Mountain Tuff in the PTn22, PTn23, and PTn24 unsaturated zone flow model layers. This breakdown, however, can not be used for this analysis because the necessary detail on stratigraphic position is not included in the fracture and fault data sets collected in the Exploratory Studies Facility (Table 3.2-2). Consequently, this analysis treats the all data from the Yucca Mountain Tuff as being part of the PTn23 unsaturated zone flow model layer.

Table 3.2-2. Summary Of Digital Data Sets For Fault And Fracture Data Collected By The DOE From The Paintbrush Nonwelded Tuff In The Exploratory Studies Facility.

Data Tracking Number	Description
GS970808314224.008	Fracture Type data from South Ramp-Tunnel at the ESF, and Yucca Mountain Project Detailed Line Survey-Data Collected from Station 65+00 to 70+00.
GS970808314224.010	Fracture Type data on South Ramp-Tunnel at the ESF, and Yucca Mountain Project Detailed Line Survey-Data Collected from Station 70+00 to 75+00.
GS970808314224.012	Fracture Type data from Detailed Line Survey-data collected from station 75+00 to 78+77 on the South Ramp at the ESF in Yucca Mountain area, 03/06/1997 to 06/17/1997.
GS971108314224.021	Revision 1 of Detailed Line Survey Data, Station 4+00 to Station 8+00, North Ramp, Exploratory Studies Facility.
GS971108314224.022	Revision 1 of Detailed Line Survey Data, Station 8+00 to Station 10+00, North Ramp, Exploratory Studies Facility.
GS971108314224.023	Revision 1 of Detailed Line Survey Data, Station 10+00 to Station 18+00, North Ramp, Exploratory Studies Facility.
MO9904MWDFPG16.000	Fracture Attitude data for full periphery geotechnical mapping of strike and dip data entry correction analysis.

Data from DLS

Once the initial extraction of DLS-based fracture and fault data was completed, separate “sheets” were used to analysis the data in different categories. The following “sheets” were developed:

1. *PTn-original* – all DLS-based fracture and fault data from ESF for PTn sorted by station position.
2. *PTn-Strike+Dip Sorted* – all DLS-based fracture and fault data from ESF for PTn separated into orientation-based fracture sets, and with Terzaghi correction applied.
3. *PTn-Displacemen*t – only fractures or faults with recorded offsets sorted by “Unsaturated Zone Flow Model Layer.”
4. *Sorted - Lithostratigraphy* – all DLS-based fracture and fault data from ESF for PTn sorted by “Lithostratigraphic Unit.”
5. *Sorted - PTn Unit* – all DLS-based fracture and fault data from ESF for PTn sorted by “Unsaturated Zone Flow Model Layer.”

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Data from FPGM

Once the initial extraction of FPGM-based fracture data was completed, separate "sheets" were used to analysis the data in different categories. The following "sheets" were developed:

1. *Original Data* – all FPGM-based fracture data from ESF for PTn sorted by station position.
2. *Original - Strike+Dip Sorted* – all FPGM-based fracture data from ESF for PTn separated into orientation-based fracture sets, and with Terzaghi correction applied.
3. *Sorted by Lithostratigraphy* – all FPGM-based fracture data from ESF for PTn sorted by "Lithostratigraphic Unit."
4. *Sorted by PTn #* – all FPGM-based fracture data from ESF for PTn sorted by "Unsaturated Zone Flow Model Layer."

Additional supporting tables and figures:

Table 3.2-3. Summary Of Exploratory Studies Facility Tunnel Length, Number, And Number Per Unit Length (P_{10}) of Fractures And Faults For Each Paintbrush Tuff Nonwelded Hydrogeologic Unit As Determined By Full-Periphery Geologic Mapping and Detailed Line Survey. The Intensity Measure P_{10} Is Defined In Dershowitz and Herda, 1992.

Unsaturated Zone Flow Model Layer	Tunnel Length, m [ft]	Full-Periphery Geologic Mapping		Detailed Line Survey			
		Fractures		Fractures		Faults	
		#	P_{10}, m^{-1} [ft^{-1}]	#	P_{10}, m^{-1} [ft^{-1}]	#	P_{10}, m^{-1} [ft^{-1}]
All	496 [1628]	809	1.6 [0.5]	340	0.7 [0.2]	126	0.3 [0.1]
PTn21	109 [358]	308	2.8 [0.9]	90	0.8 [0.3]	24	0.2 [0.1]
PTn22	9 [30]	6	0.7 [0.2]	2	0.2 [0.1]	2	0.2 [0.1]
PTn23	2 [8]	5	2.2 [0.7]	5	2.2 [0.7]	2	0.9 [0.3]
PTn24	45 [147]	45	1.0 [0.3]	19	0.4 [0.1]	15	0.3 [0.1]
PTn25	131 [431]	144	1.1 [0.3]	80	0.6 [0.2]	22	0.2 [0.1
PTn26	200 [655]	301	1.5 [0.9]	144	0.7 [0.3]	61	0.3 [0.1]

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Table 3.2-4. Summary Of Observed (i.e., Raw) Fracture Spacings And Intensities (i.e., Inverse Of Spacing) From The PTn Interval Exposed In The Exploratory Studies Facility Based On Measurements Collected Via The Full-Periphery Geologic Mapping Technique. Spacing Was Calculated With An Upper Bound Of 10 m [38 ft] {i.e., Spacing Was Not Calculated for Fracture Pairs That Were ≥10 m [38 ft] Apart}.

Unsaturated Zone Flow Model Layer	Number (%)	Measure	Spacing (m)	Intensity (m^{-1})
All	809 (100%)	Mean	0.59	1.71
		Median	0.32	3.12
		Std. Dev	0.75	1.33
PTn21	308 (38%)	Mean	0.36	2.76
		Median	0.21	4.76
		Std. Dev	0.46	2.19
PTn22	6 (<1%)	Mean	0.82	1.22
		Median	0.12	8.33
		Std. Dev	1.45	0.69
PTn23	5 (<1%)	Mean	0.52	1.91
		Median	0.29	3.45
		Std. Dev	0.65	1.53
PTn24	45 (6%)	Mean	1.01	0.99
		Median	0.76	1.32
		Std. Dev	0.86	1.16
PTn25	144 (18%)	Mean	0.93	1.08
		Median	0.62	1.61
		Std. Dev	1.01	0.99
PTn26	301 (37%)	Mean	0.54	1.85
		Median	0.34	2.94
		Std. Dev	0.67	1.50

Note: PTn21 consists of Tpcpv1; PTn22 consists of Tpbt4; PTn23 consists of Tpy; PTn24 consists of Tpbt3; PTn25 consists of Tpp; PTn26 consists of Tpbt2, Tptrv3, and Tptrv2.

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Table 3.2-6. Summary Of Observed (i.e., Raw) Fracture Spacings, Intensities (i.e., Inverse Of Spacing), And Trace Lengths From The PTn Interval Exposed In The Exploratory Studies Facility Based On Measurements Collected Via The Detailed Line Survey Technique. Spacing Was Calculated With An Upper Bound Of 10 m [38 ft] {i.e., Spacing Was Not Calculated for Fracture Pairs That Were ≥10 m [38 ft] Apart}.

Unsaturated Zone Flow Model Layer	Number (%)	Measure	Spacing (m)	Intensity (m^{-1})	Trace Length (m)
All	340 (100%)	Mean	1.27	0.79	3.55
		Median	0.62	1.61	2.20
		Std. Dev	1.61	0.62	4.68
PTn21	90 (26%)	Mean	1.48	0.67	3.20
		Median	0.67	1.49	2.50
		Std. Dev	1.88	0.53	2.79
PTn22	2 (<1%)	Mean	0.03	33.33	3.09
		Median	0.03	33.33	3.09
		Std. Dev	n.a.	n.a.	2.06
PTn23	5 (1%)	Mean	0.31	3.20	2.24
		Median	0.28	3.64	0.91
		Std. Dev	0.26	3.91	2.32
PTn24	19 (6%)	Mean	2.04	0.49	4.80
		Median	0.91	1.10	2.76
		Std. Dev	2.13	0.47	5.61
PTn25	80 (24%)	Mean	1.58	0.63	5.56
		Median	0.96	1.04	3.56
		Std. Dev	1.74	0.58	6.84
PTn26	144 (42%)	Mean	0.91	1.10	2.86
		Median	0.40	2.47	1.52
		Std. Dev	1.16	0.86	4.00

Note: PTn21 consists of Tpcpv1; PTn22 consists of Tpbt4; PTn23 consists of Tpy; PTn24 consists of Tpbt3; PTn25 consists of Tpp; PTn26 consists of Tpbt2, Tptrv3, and Tptrv2.

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Table 3.2-5. Comparison Of Uncorrected And True (i.e., Corrected) Spacing And Intensity (i.e., Inverse Of Spacing) For The 809 Fractures From The PTn Interval In The Exploratory Studies Facility Based On Data Collected Via Full-Periphery Geologic Mapping Technique. Fracture Sets Determined From Stereographic Analysis Using Criteria Specified Below. Spacing Was Calculated With An Upper Bound Of 10 m [38 ft] {i.e., Spacing Was Not Calculated for Fracture Pairs That Were ≥10 m [38 ft] Apart}.

Set	Number (%)	Mean Orientation (Strike/Dip)	Fisher Dispersion Coefficient	Measure	Uncorrected		True	
					Spacing (m)	Intensity (m^{-1})	Spacing (m)	Intensity (m^{-1})
1	661 (82%)	186°/78°	8.571	Mean	0.70	1.43	0.64	1.55
				Median	0.38	2.63	0.34	2.94
				Std. Dev	0.89	1.13	0.82	1.23
2	94 (11%)	106°/83°	4.876	Mean	2.46	0.41	0.67	1.50
				Median	1.61	0.62	0.45	2.20
				Std. Dev	2.40	0.42	0.64	1.56
3	54 (7%)	003°/13°	13.515	Mean	2.71	0.37	0.67	1.50
				Median	1.87	0.53	0.47	2.14
				Std. Dev	2.67	0.37	0.65	1.54

Set 1 = Fracture strikes of 145° to 235° (325° to 055°) and dips of >40°.
Set 2 = Fracture strikes of 056° to 144° (236° to 324°) and dips of >40°.
Set 3 = Fractures with dips of ≤40°.

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Table 3.2-7. Comparison Of Uncorrected And True (i.e., Corrected) Spacing And Intensity (i.e., Inverse Of Spacing), And Trace Length For The 340 Fractures From The PTn Interval In The Exploratory Studies Facility Based On Data Collected Via Detailed Line Survey Technique. Fracture Sets Determined From Stereographic Analysis Using Criteria Specified Below. Spacing Was Calculated With An Upper Bound Of 10 m [38 ft] {i.e., Spacing Was Not Calculated for Fracture Pairs That Were ≥10 m [38 ft] Apart}.

Set	Number (%)	Mean Orientation (Strike/Dip)	Fisher Dispersion Coefficient	Measure	Uncorrected		True		Trace Length (m)
					Spacing (m)	Intensity (m^{-1})	Spacing (m)	Intensity (m^{-1})	
1	282 (83%)	188°/80°	8.310	Mean	1.32	0.76	1.23	0.81	3.57
				Median	0.73	1.37	0.67	1.50	2.26
				Std. Dev	1.56	0.64	1.47	0.68	4.32
2	41 (12%)	127°/88°	7.857	Mean	2.60	0.39	1.08	0.93	2.49
				Median	1.60	0.63	0.60	1.65	1.60
				Std. Dev	2.89	0.35	1.33	0.75	1.99
3	17 (5%)	012°/11°	16.617	Mean	2.43	0.41	0.59	1.70	5.89
				Median	0.89	1.13	0.21	4.67	3.50
				Std. Dev	2.54	0.39	0.62	1.63	10.86

Set 1 = Fracture strikes of 150° to 240° (330° to 060°) and dips of >40°.
Set 2 = Fracture strikes of 061° to 149° (241° to 329°) and dips of >40°.
Set 3 = Fractures with dips of ≤40°.

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Table 3.2-8. Summary Of Observed (i.e., Raw) Fracture Spacings, Intensities (i.e., Inverse Of Spacing), Trace Lengths, And Offsets From Faults In The PTn Interval Exposed In The Exploratory Studies Facility Based On Measurements Collected Via The Detailed Line Survey Technique. Spacing Was Calculated With An Upper Bound Of 10 m [38 ft] {i.e., Spacing Was Not Calculated for Fracture Pairs That Were ≥10 m [38 ft] Apart}.

Unsaturated Zone Flow Model Layer	Number (%)	Measure	Spacing (m)	Intensity (m^{-1})	Trace Length (m)	Offset (cm)
All	126 (100%)	Mean	2.23	0.45	5.38	37
		Median	1.30	0.77	3.25	15
		Std. Dev	2.14	0.47	5.74	68
PTn21	24 (19%)	Mean	1.96	0.51	3.45	61
		Median	1.19	0.84	3.07	17
		Std. Dev	1.92	0.52	2.19	101
PTn22	2 (2%)	Mean	0.03	33.33	3.09	12
		Median	0.03	33.33	3.09	12
		Std. Dev	n.a.	n.a.	2.06	5
PTn23	2 (2%)	Mean	1.25	0.80	4.39	25
		Median	1.25	0.80	4.39	25
		Std. Dev	n.a.	n.a.	2.49	21
PTn24	15 (12%)	Mean	1.68	0.60	5.36	32
		Median	0.88	1.14	2.80	15
		Std. Dev	1.71	0.58	6.01	38
PTn25	22 (17%)	Mean	3.33	0.30	9.25	42
		Median	3.27	0.31	5.65	25
		Std. Dev	2.19	0.46	7.42	43
PTn26	61 (48%)	Mean	1.74	0.58	4.78	27
		Median	1.00	1.00	2.95	11
		Std. Dev	1.80	0.55	5.52	66

Note: PTn21 consists of Tpcpv1; PTn22 consists of Tpbt4; PTn23 consists of Tpy; PTn24 consists of Tpbt3; PTn25 consists of Tpp; PTn26 consists of Tpbt2, Tptrv3, and Tptrv2.

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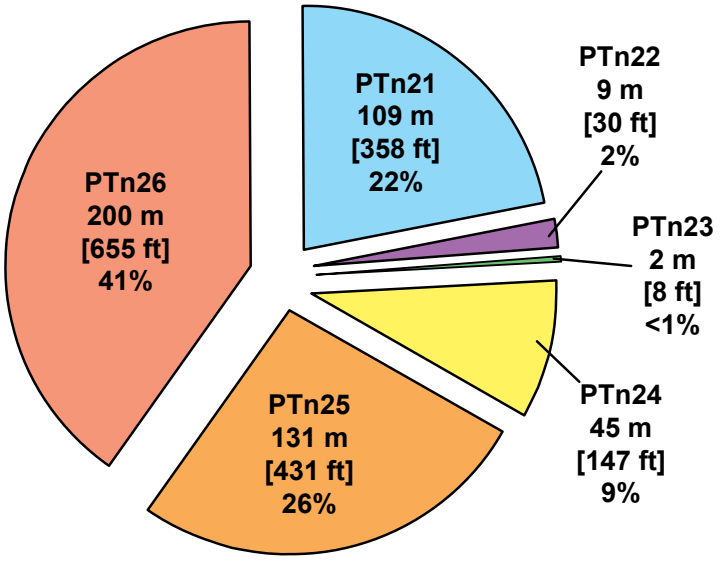

Figure 3.2-6 Summary Of Exposed Length and Percentage For Each Unsaturated Zone Flow Model Layer Of The Paintbrush Tuff Nonwelded Hydrogeologic Unit As Exposed In The Exploratory Studies Facility. Total Exposed Length Is 496 m [1628 ft].

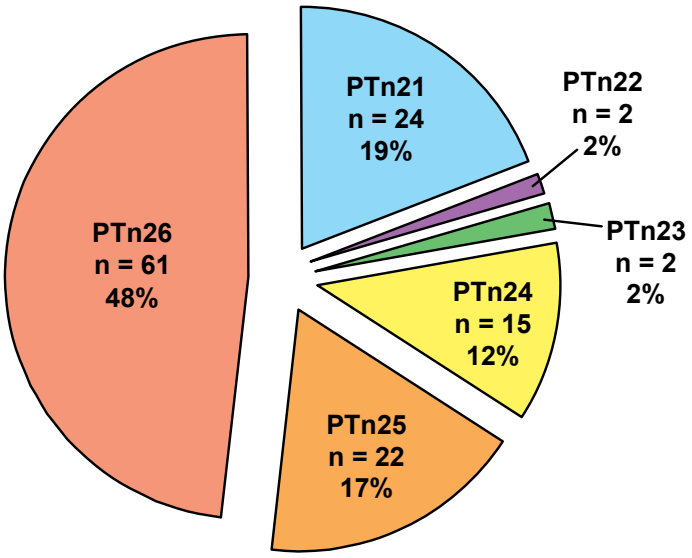

Figure 3.2-7 Summary Of Number Of Faults And Percentage For Each Unsaturated Zone Flow Model Layer Of The Paintbrush Tuff Nonwelded Hydrogeologic Unit As Exposed In The Exploratory Studies Facility. Fault Data Collected Via Detailed Line Survey Technique (Total of 126 Measurements).

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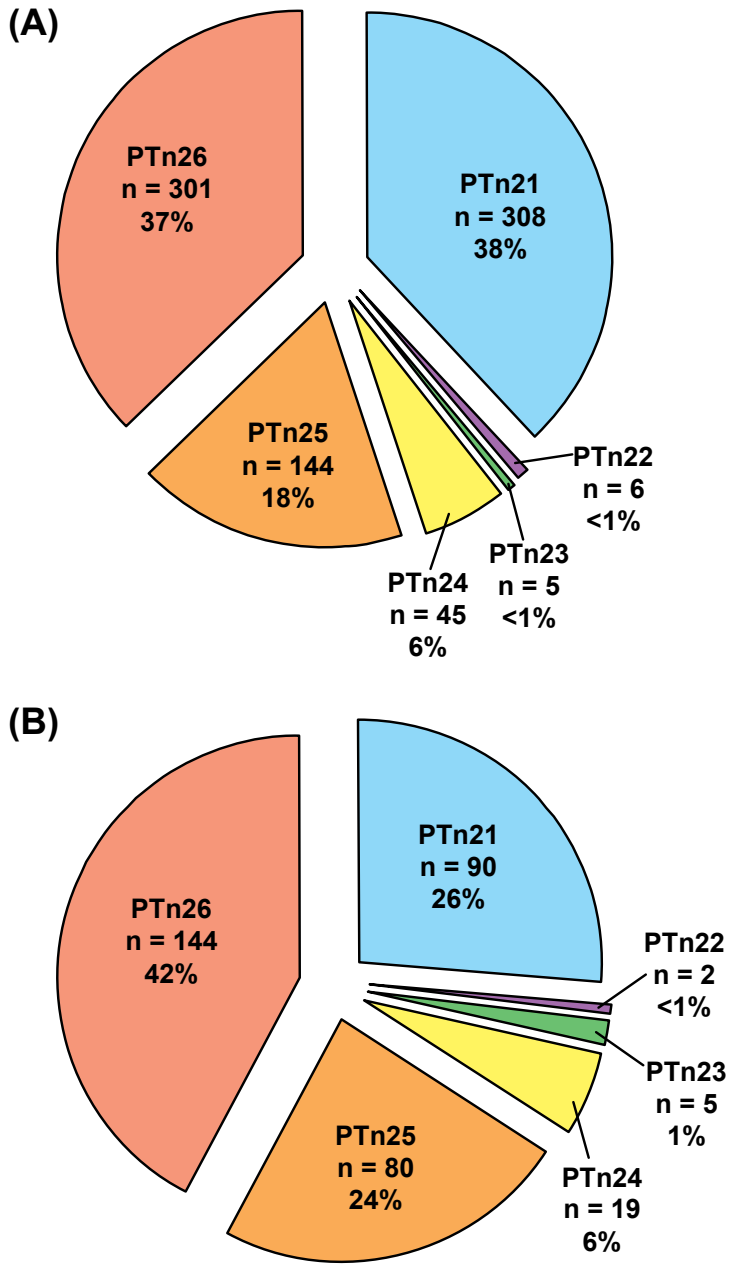

Figure 3.2-8 Summary Of Number Of Fractures And Percentage For Each Unsaturated Zone Flow Model Layer Of The PTn As Exposed In The Exploratory Studies Facility. (A) Fracture Data Collected Via Full-Periphery Geologic Mapping Technique (Total of 809 Measurements). (B) Fracture Data Collected Via Detailed Line Survey Technique (Total of 340 Measurements).

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PRELIMINARY ANALYSIS OF FAULT AND FRACTURE DATA FROM ALCOVE 4

During the NRC's review of "The Nature of Flow in the Faulted and Fractured Paintbrush Nonwelded Hydrogeologic Unit" (Intermediate Milestone 06002.01.262.640), the following question was raised:

> The DOE performed injection tests in Alcove 4. Can you comment on the representativeness of Alcove 4 in terms of all the data presented in section 3.2?

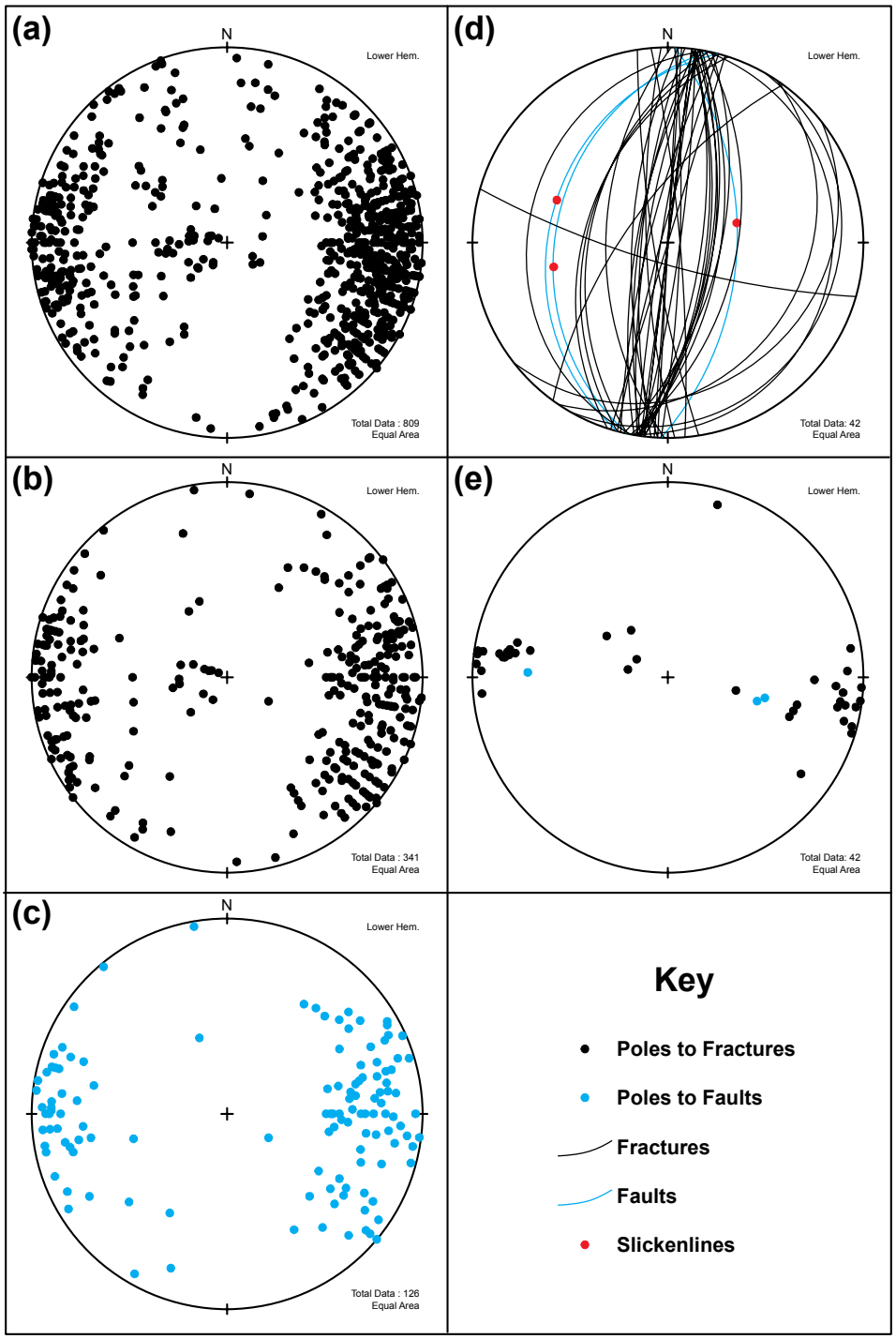
A preliminary analysis of fault and fracture data from Alcove 4 was initiated to address this question. It was determined that the DLS data for Alcove 4 is reported by Barr et al. (1996) to be contained as part of DTN GS960908314224.020. A "ZIP" file labelled with this DTN number was provided to CNWRA as part of two CD's containing ESF and ECRB fracture data, but it was found that the file on the CD contains only FPGM files for the north ramp portion of the ESF and the FPGM file for Alcoves 3 and 4 (filename is "alc3_4.dwg"). An exhaustive search of the data provided by DOE has not found the Alcove 4 DLS data (although the CNWRA was provided with DLS data for Alcoves 2, 3, 5, and 6).

To attempt to address the NRC's question, the fracture and fault data documented on the Alcove 4 FPGM were manually extracted and input into a spreadsheet file (filename (Alcove-4_FPGM.xls"). The FPGM contains 39 recorded fracture orientations (strike & dip) and 3 faults (strike, dip, & rake). The figure on the next page contains stereonet plots of the fractures (part d) and faults (part e) from Alcove 4 FPGM with a comparison to the fractures from the PTn in the ESF (part a = FPGM; part b = DLS) and the faults from the PTn in the ESF (part c).

Based on this preliminary analysis, we conclude that fractures and faults recorded on the FPGM from Alcove 4 have similar orientations to the fractures and faults from the PTn as characterized in the ESF. The majority of Alcove 4 fractures strike north-south and are steeply dipping ($\geq$70°). Comparison of fracture intensity between Alcove 4 and the rest of the PTn is not possible at this time.

Documents Cited

Barr, D.L., T.C. Moyer, W.L. Singleton, A.L. Albin, R.C. Lung, A.C. Lee, S.C. Beason, and G.L.W. Eatman. "Geology of the North Ramp—Station 4+00 to 28+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada." DOE Report DTN GS960908314224.020. Denver, Colorado: Bureau of Reclamation and U.S. Geological Survey. 1996.



Equal-area stereonet plots fracture and fault data for Paintbrush nonwelded hydrogeologic unit. (a) Poles to fractures from full-periphery geologic mapping of PTn from north and south ramps of ESF. (b) Poles to fractures from detailed line survey of PTn from north and south ramps of ESF. (c) Poles to faults from detailed line survey of PTn from north and south ramps of ESF. (d) Fractures (black) and faults (blue) from full-periphery geologic mapping of Alcove 4. Red circles are measured slip indicators (i.e., slickenlines on faults. (e) Poles to fractures and faults from full-periphery geologic mapping of Alcove 4.

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