



## **User Guide**

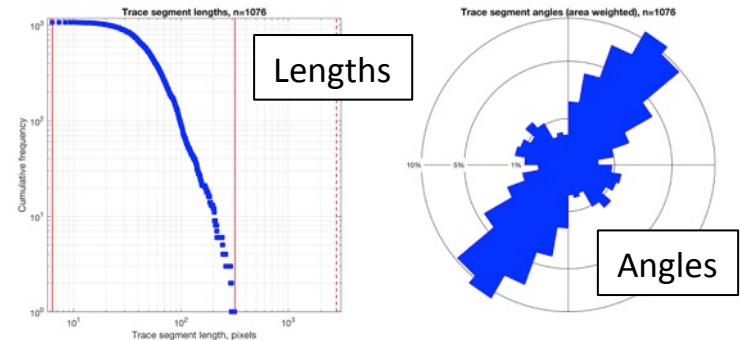
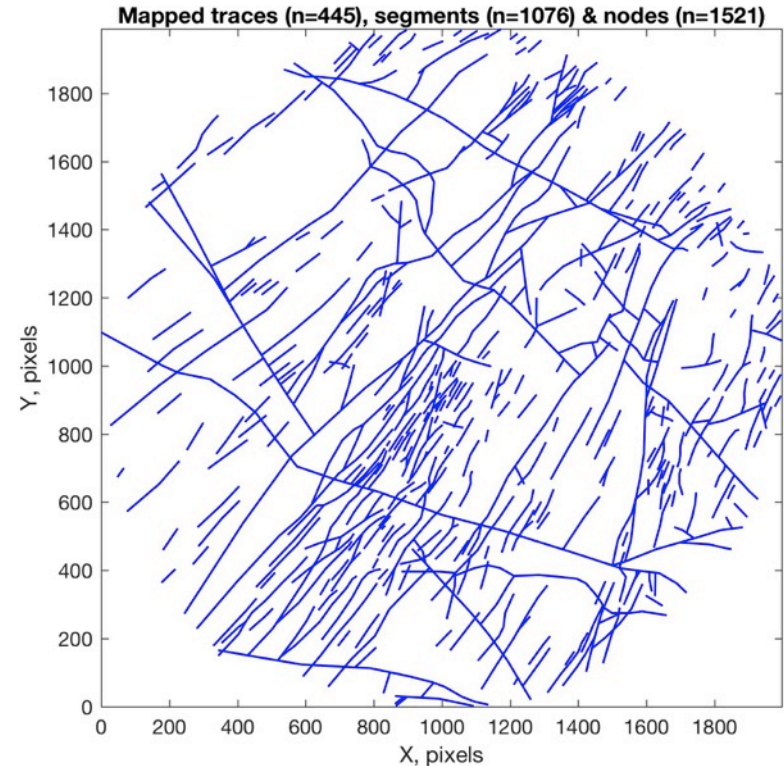
Version 1.6, August 2016

# Introduction

**FracPaQ** is an open source toolbox written in MATLAB™ and publicly available on GitHub and Mathworks FileExchange. The initial release version is v1.6. **FracPaQ** is designed to quantify fracture patterns in rock. The user supplies either an image file of fractured rock or a text file of traced fractures and their (x,y) coordinates.

From either kind of input, the code calculates the fracture lengths, angles, intensity, density and connectivity. These are displayed as maps and graphs, and saved as .tif files. An estimate is made of permeability in 2D using a simple parallel-plate model and assuming constant aperture.

We hope that the code will enable researchers to quantify fracture patterns in an open, objective, and consistent way. **We also hope that people will contribute new functions and new tools, and report any bugs 😊**



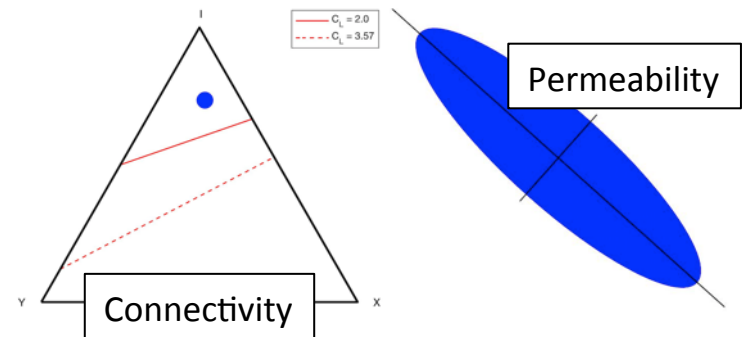
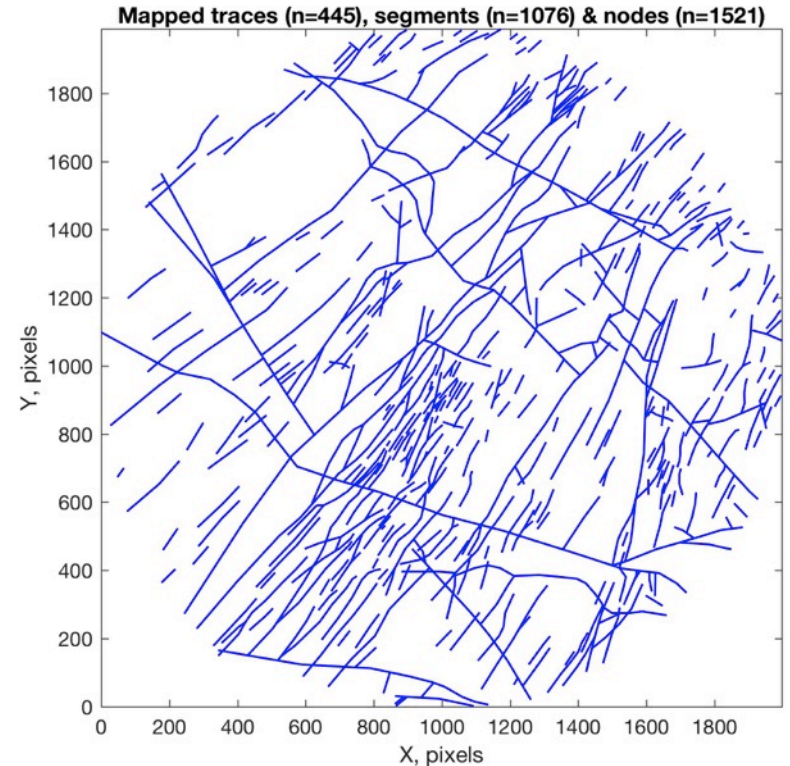


# Introduction

**FracPaQ** is written in MATLAB™ and totals over 4,000 lines of code. As in any software project of this scale, there will be ‘bugs’ – i.e. coding errors. If you encounter a bug, please let us know – through GitHub, Mathworks FileExchange or by e-mail ([d.healy@abdn.ac.uk](mailto:d.healy@abdn.ac.uk)); please provide as many details as you can, including (where possible) a screen shot of the error, the input file you were using at the time, and the MATLAB version.

**FracPaQ** uses code written by others: **lineSegmentIntersect.m** by U. Murat Erdem and **readtext.m** by Peder Axensten (both available on Mathworks FileExchange).

The handling of image file input in **FracPaQ** also uses functions from the Image Processing Toolbox (version 9.4), a MATLAB™ add-on.



## Installing FracPaQ

You can get all the source code and run it directly from the MATLAB command window.

The source code and this User Guide are available on **GitHub**:

<http://davehealy-aberdeen.github.io/FracPaQ/>

and on the **Mathworks FileExchange**:

<https://uk.mathworks.com/matlabcentral/fileexchange/58860-davehealy-aberdeen-fracpaq>

Steps:

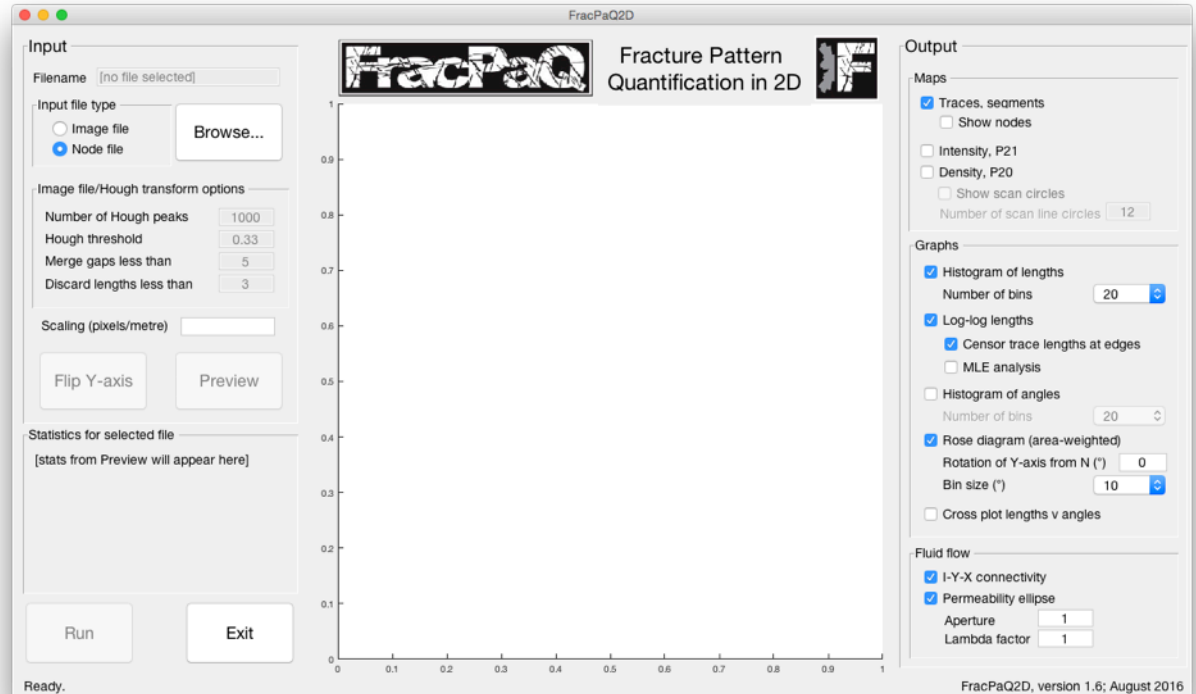
1. Download the source code as a .zip or .tar.gz file, and extract all of the files
2. Put all of these files into a single folder
3. Start MATLAB (NB. we developed FracPaQ using MATLAB R2016a)
4. Set the current working folder in MATLAB to the folder you installed the code in
5. At the MATLAB command prompt type 'guiFracPaQ2D' and hit Enter

Output files (graphs, maps and data) will appear in the same folder.

## Starting FracPaQ

There is only one window in the application (see right). The window can be minimised or closed using the standard GUI controls (top left in the Mac OS X version shown).

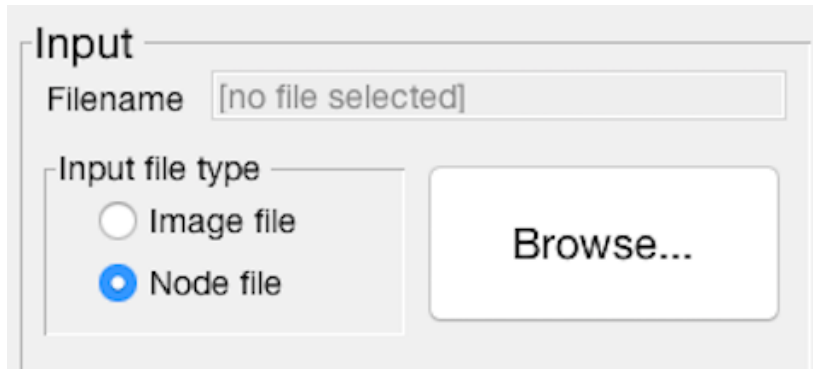
Input parameters are on the left side, and output options are on the right. The central area is for previewing the input data as a fracture trace map.



To get started, click **Browse...** to see a list of possible input files in the current working folder. Then click **Preview** to open the data file and view the traces in the main window; basic statistics on the pattern are also shown (lower left box). Select the Outputs you need (right hand side), and then click **Run** to produce the selected maps and graphs. Each output is shown in a separate figure window, and saved as a separate .jpeg in the current folder.

Click **Exit** to quit **FracPaQ**.

## Choosing an input file



Click **Browse...** to select an input file. The file types shown are filtered to those with file extensions \*.txt, \*.jpeg, \*.jpg, \*.tiff and \*.tif.

If you select a text (\*.txt) file of (x,y) fracture trace nodes, the Input file type changes automatically to 'Node file'.

If you choose a graphic file format (\*.jpeg, \*.jpg, \*.tiff, \*.tif), the Input file type changes to 'Image file'.

You can manually override these defaults if you wish.

\*.txt file example

325.5	424.6	340.6	424.2	360.1	428.4									
340.6	424.2	360.4	421.4	372.7	420.6									
372.7	420.6	392.1	418.3											
344.6	418.7	362.1	421.3											
392.1	418.3	403.2	417.9											
243.5	425.4	263.7	427	283.9	427.3	304.5	427							
279.5	432.9	297.8	431.7	310.1	432.5	325.5	435.2	339.8	436	353.3	438			
360.1	428.4	378.3	447.1	383	453.8	387.8	460.1							
326.3	474	345.4	466.9	361.6	459	369.1	455.4							
360.4	445.9	369.1	455.4											
369.1	455.4	377.1	462.9											
354.6	462.4	365.2	463.3	377.1	462.9									
377.1	462.9	393.3	457.4	406.4	452.6									
356.1	443.2	373.5	446.7											
277.6	370.5	270.8	411.9	269.2	442.4	268	475.5	269.6	499.3					
124.9	434.5	145.5	436.4	163.8	435.6	180.4	436.8	190.7	437.6					
185.2	439.6	213.3	446.7	240.7	452.6	256.9	455.8	268.7	455.8					
283.1	462.5	304.9	463.3	315.2	464.1									
247.3	400.5	263.7	402.1	281.9	402.5	296.6	401.7							
300.2	404.4	316	405.2											

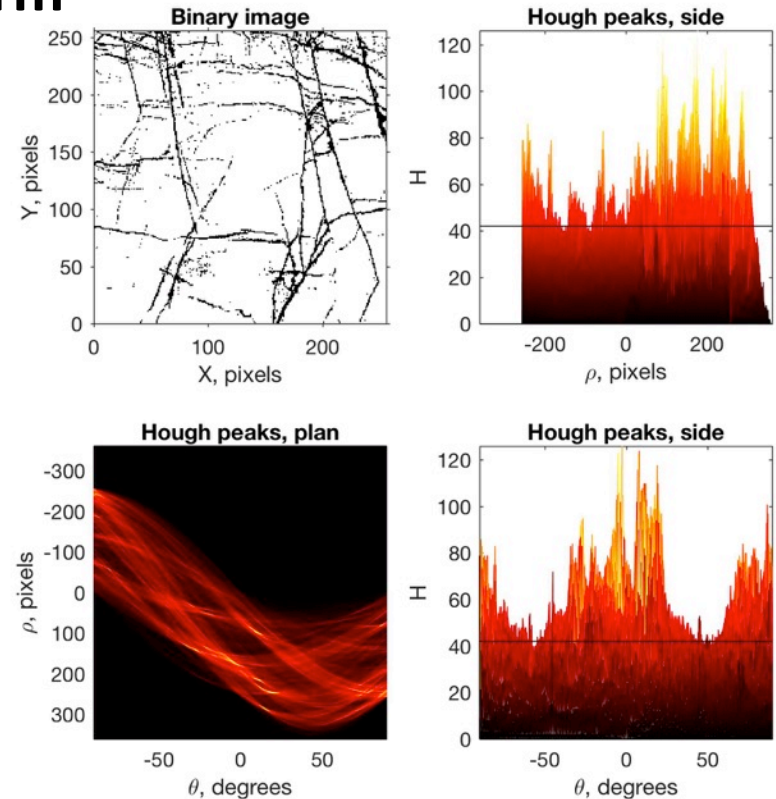
Shown above is an **example of a \*.txt file** for input. The file contains (x,y) nodes along each fracture trace. The (x,y) data are **tab-delimited**, and **each fracture trace is on one line**. There is a minimum of 4 columns for each line (i.e. each fracture trace) – (x1, y1) for node 1 and (x2, y2) for node 2.

A fracture trace can be made of many segments; in the example shown above the longest trace (line 7) has 5 segments, bounded by 6 nodes – i.e. 12 columns = 6 x 2 (x,y) pairs.

## Image file input – the Hough transform

FracPaQ can also read binary **image files** as input. Two examples are provided, **MacduffBinary.tif** and **OrkneyBinary.tif**. The code uses a Hough transform to find straight lines within the pixels. The user can choose the values at which these lines are merged (if they are close enough together) or discarded (if they are too short). More details on the Hough transform method can be found in the MATLAB Help documentation.

The key parameters that affect the number and length of the fracture traces found are the number of **peaks** and the **threshold**. Using the Hough transform is a 'trial and error' procedure: load an image file and click **Preview**. Then use the graphs (shown on the right, created as Figure 1) and the trace map displayed in the main window to tune the Hough transform parameters. Set the **threshold** to a value between 0.0 and 1.0 that captures only the significant peaks (in orange/yellow on the graphs). 0.33 is a good start.



**NB:** the Hough transform method can **only find straight line fractures** each made of a single trace; multi-segment traces cannot be found.  $N_{\text{traces}} = N_{\text{segments}}$  for this method.

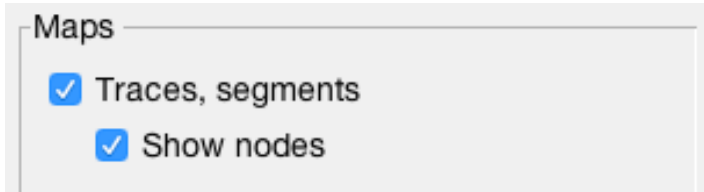
## Text file input – conversion from .svg format

Also included with **FracPaQ** is a Unix shell script to convert scaleable vector graphics (\*.svg) files into the correct tab-delimited text (\*.txt) file format. Standard graphics packages, such as Adobe Illustrator, CorelDraw and Inkscape, can all produce .svg files. Typically, the user imports an image or map of fractured rock, and then traces the fractures onto a new layer in the software. After deleting the original image, the traces can be saved as .svg format. **We recommend using .svg format version 1.1.**

The shell script reads in the .svg file of your choice and produces a new .txt file with each fracture on a separate line, and all the (x,y) nodes separated by tabs. For Windows users, there may be support for running Unix shell scripts under Windows 10.



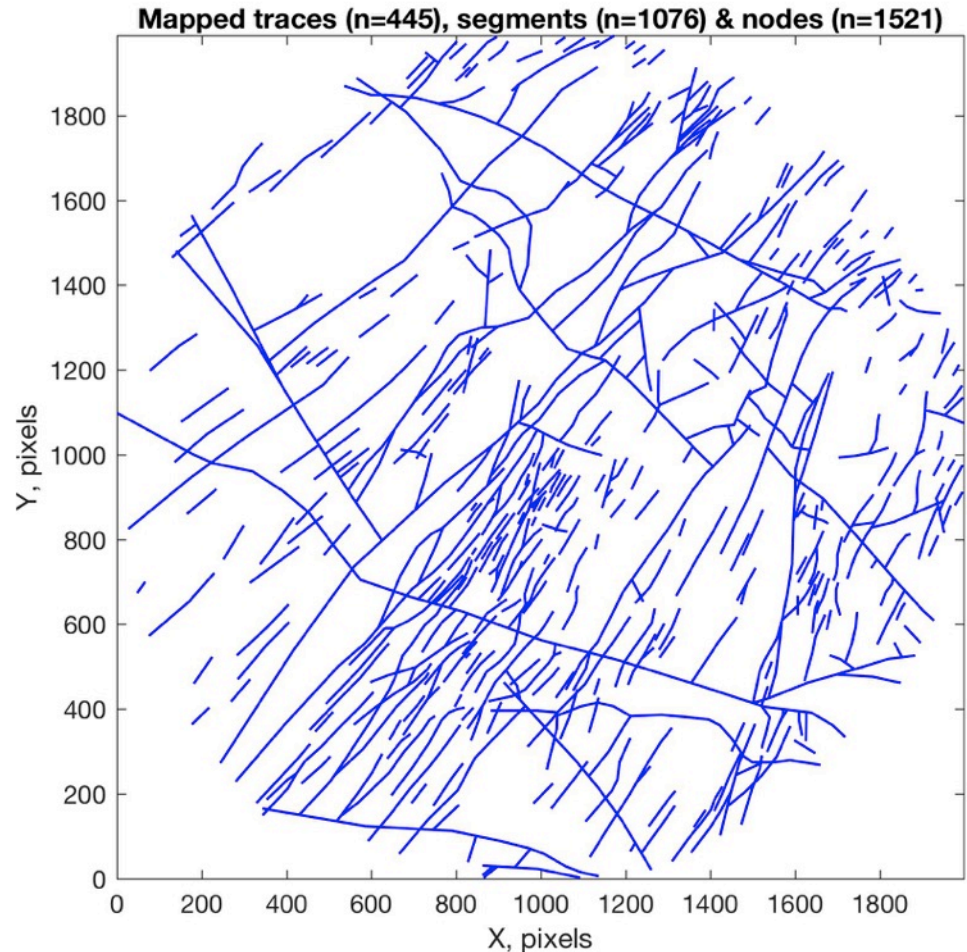
## Maps – Traces, segments



Click on the checkbox “Traces, segments” in the Maps output panel to see a map of all fracture traces and segments. The numbers of traces, segments and nodes (i.e. the end points of traces and segments) are shown in the figure title.

This plot is saved in the current folder as **FracPaQ2D\_tracemap.tif**, at a default resolution of 300 dpi.

The figure is produced by the script **guiFracPaQ2Dtracemap.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.



## Maps – Traces, segments; Show nodes

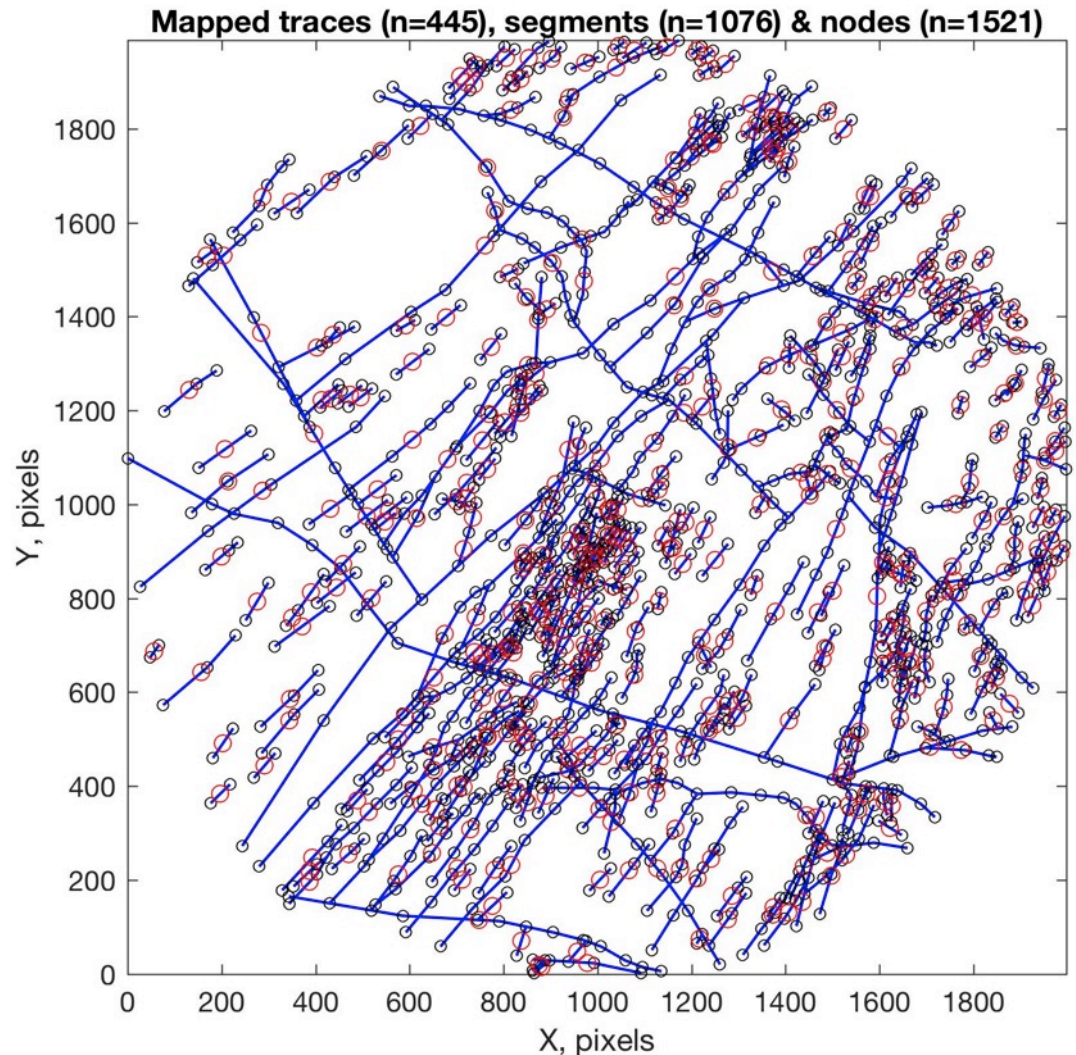
### Maps

- ☒ Traces, segments
- ☒ Show nodes

Click on the checkbox “Traces, segments” and also check “Show nodes” to see a map of all fracture traces and segments **with all the nodes displayed**. The numbers of traces, segments and nodes (i.e. the end points of traces and segments) are shown in the figure title.

Trace and segment end nodes are shown with black circles, and trace centres are shown with red circles.

This plot is saved in the current folder as **FracPaQ2D\_tracemap.tif**, at a default resolution of 300 dpi. The figure is produced by the script **guiFracPaQ2Dtracemap.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.





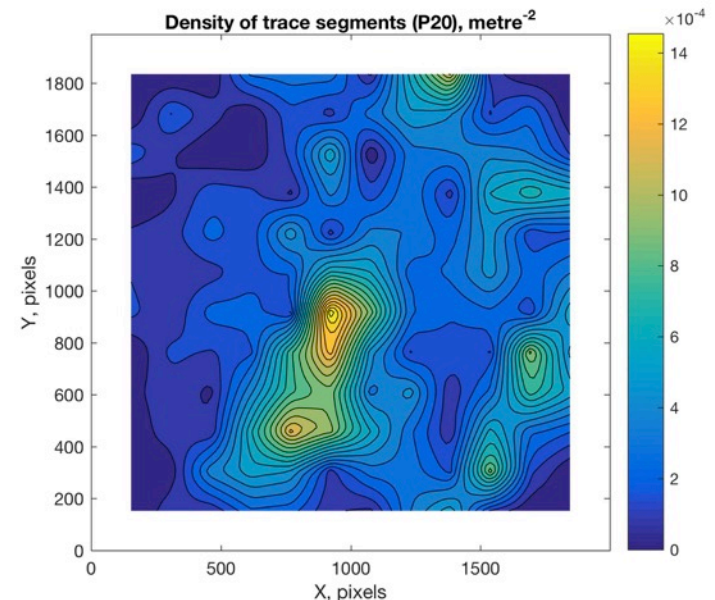
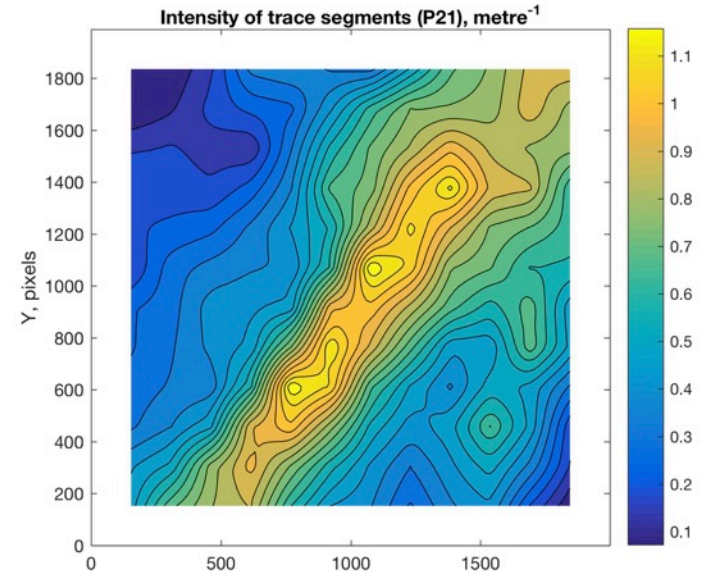
## Maps – Intensity (P21), Density (P20)

☒ Intensity, P21  
☒ Density, P20  
☐ Show scan circles  
 Number of scan line circles

Click on the checkbox “Intensity, P21” and/or “Density, P20” to see maps of fracture intensity and/or density. These contour maps are produced from the fracture segment data using the circular scan line method of Mauldon et al. (2001).

The code places scan circles (using the number in the text box) in the x- and y-directions, and counts the intersections of fracture segments with the circle perimeter ( $n$ ), and the number of segments that terminate inside the circle ( $m$ ). These measures are used to estimate Intensity (units of  $L^{-1}$ ) and Density (units of  $L^{-2}$ ) from the equations in Mauldon et al. (2001). P21 and P20 refer to the measures used by Dershowitz & Herda (1992).

These plots are saved in the current folder as **FracPaQ2D\_intensityP21.tif** and **FracPaQ2D\_densityP20.tif**, at a default resolution of 300 dpi. The figure is produced by the script **guiFracPaQ2Dpattern.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.



## Graphs – Lengths

☐ Histogram of lengths

Number of bins

20

☐ Log-log lengths

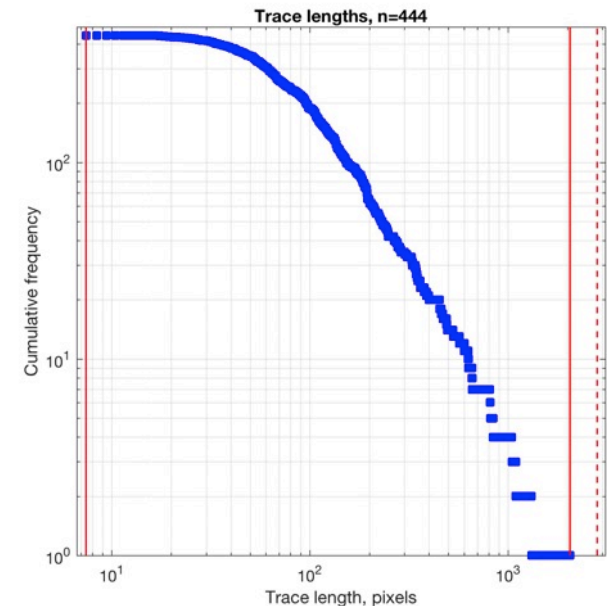
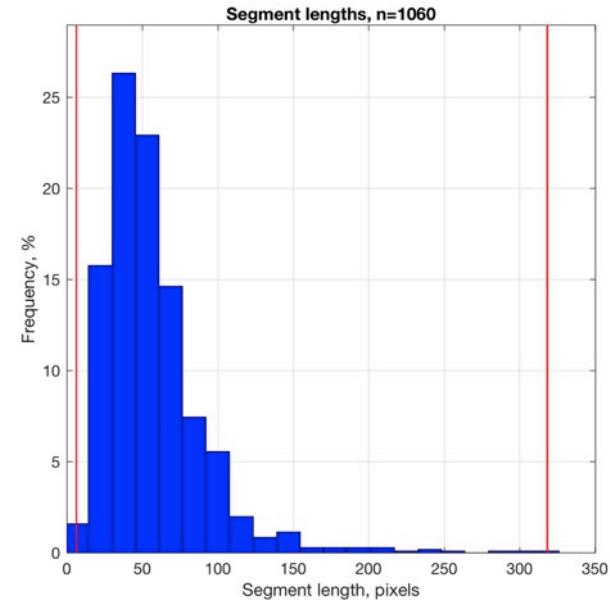
☐ Censor trace lengths at edges

☐ MLE analysis

Click on the checkbox “Histogram of lengths” and/or “Log-log lengths” to see a histogram and/or log-log plots of fracture lengths. **Separate plots are produced for fracture traces** (trace length = sum of segment lengths) **and fracture segments**. Select the number of bins for the histogram from the drop-down list.

Check “Censor trace lengths at edges” to remove from the graphs any fractures with nodes on the edges of the trace map area. The red lines on the graphs show the min, max and max possible (dotted) lengths.

The plots are saved in the current folder as **FracPaQ2D\_\*length.tif**, at a default resolution of 300 dpi. The figures are produced by the script **guiFracPaQ2Dlength\_new.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.





# Graphs – MLE Statistical Analysis

☐ Histogram of lengths

Number of bins

20

☐ Log-log lengths

☐ Censor trace lengths at edges

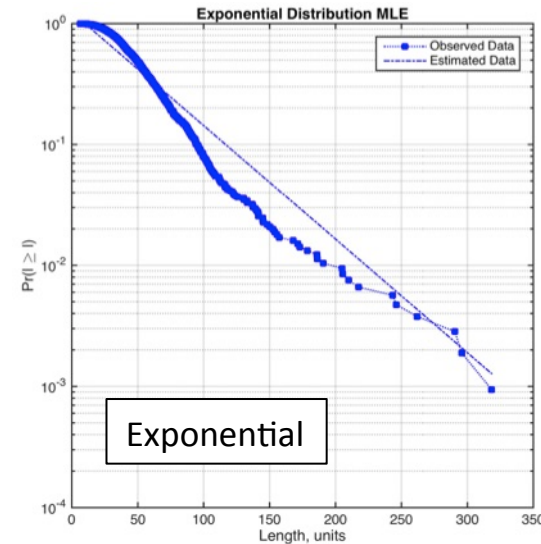
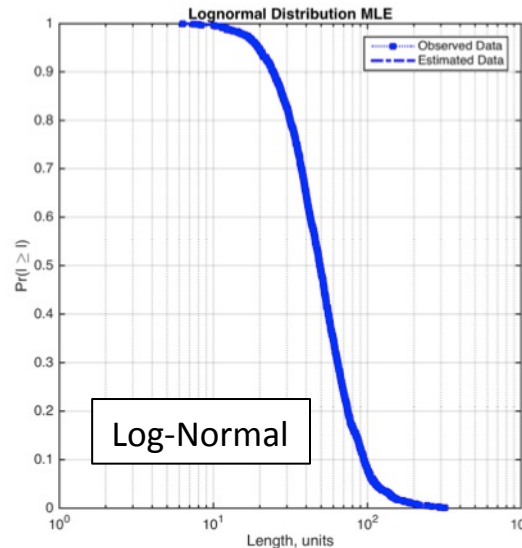
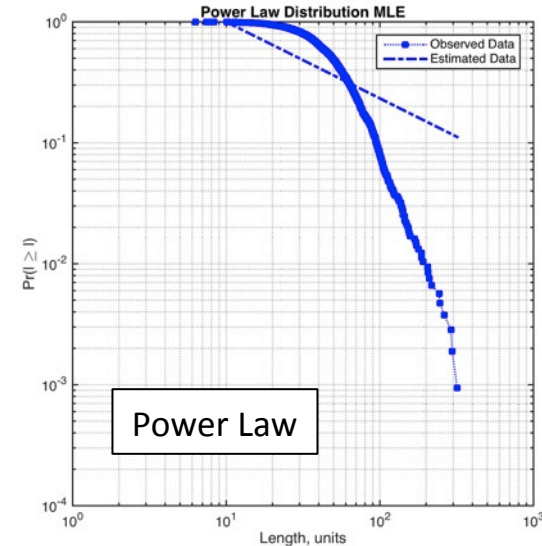
☐ MLE analysis

Click on the checkbox “MLE analysis” to perform a Maximum Likelihood Estimation (MLE) for fracture trace and segment lengths. Separate plots are produced for three possible underlying statistical distributions: Power Law, Log-Normal and Exponential. See Clauset et al. (2007) and Rizzo et al. (in review) for further details on MLE.

The plots for fracture segments are saved in the current folder as

**FracPaQ2Dlengths\_Fitting\*.tif**, at a default resolution of 300 dpi. The figures are produced by the script

**guiFracPaQ2Dlength\_new.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.



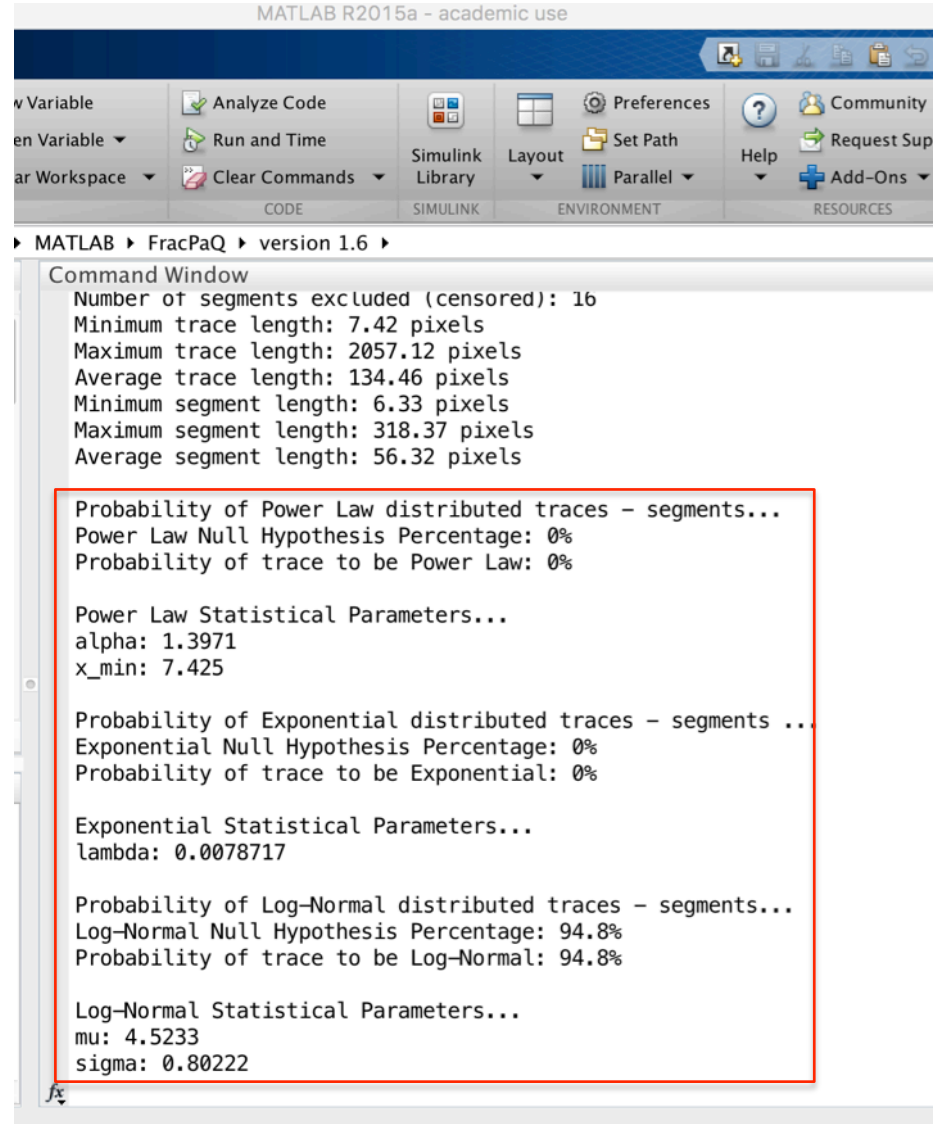
## Graphs – MLE Statistical Analysis

### Graphs

- ☒ Histogram of lengths
- ☒ Log-log lengths
- ☐ Censor trace lengths at edges
- ☒ MLE analysis

The MLE plots are supplemented with text outputs in the MATLAB™ Command Window. For each of the 3 distributions, the corresponding statistical parameters are given and the probability – expressed in % and calculated based on a Kolmogorov-Smirnoff (KS) test – that the analysed fracture lengths are distributed according to one of the distributions.

More details and relative references, can be found in the functions **fitting\*.m** called by **guiFracPaQ2Dlength\_new.m**. Edit this script to change the variables 'uc' and 'lc' to cut off a certain percentage from the beginning ('uc') % or the end ('lc') of the data set. Default values are 0% cut-off.



```

MATLAB R2015a - academic use

Command Window
MATLAB > FracPaQ > version 1.6 >

Number of segments excluded (censored): 16
Minimum trace length: 7.42 pixels
Maximum trace length: 2057.12 pixels
Average trace length: 134.46 pixels
Minimum segment length: 6.33 pixels
Maximum segment length: 318.37 pixels
Average segment length: 56.32 pixels

Probability of Power Law distributed traces - segments...
Power Law Null Hypothesis Percentage: 0%
Probability of trace to be Power Law: 0%

Power Law Statistical Parameters...
alpha: 1.3971
x_min: 7.425

Probability of Exponential distributed traces - segments ...
Exponential Null Hypothesis Percentage: 0%
Probability of trace to be Exponential: 0%

Exponential Statistical Parameters...
lambda: 0.0078717

Probability of Log-Normal distributed traces - segments...
Log-Normal Null Hypothesis Percentage: 94.8%
Probability of trace to be Log-Normal: 94.8%

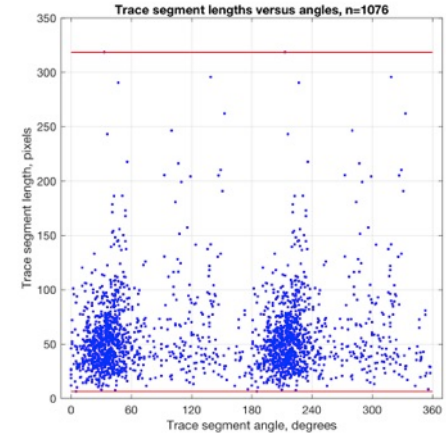
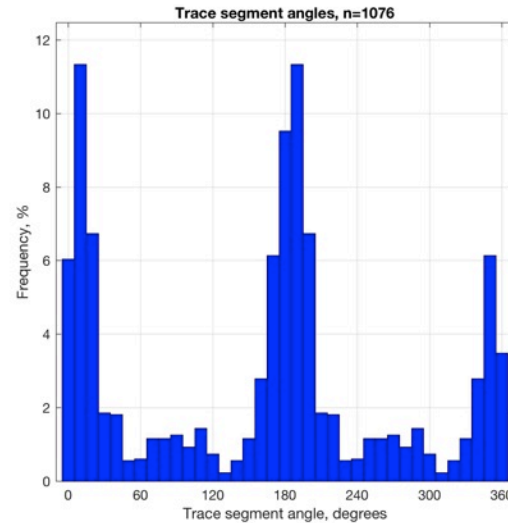
Log-Normal Statistical Parameters...
mu: 4.5233
sigma: 0.80222
  
```

## Graphs – Angles (Orientations)

☒ Histogram of angles  
 Number of bins

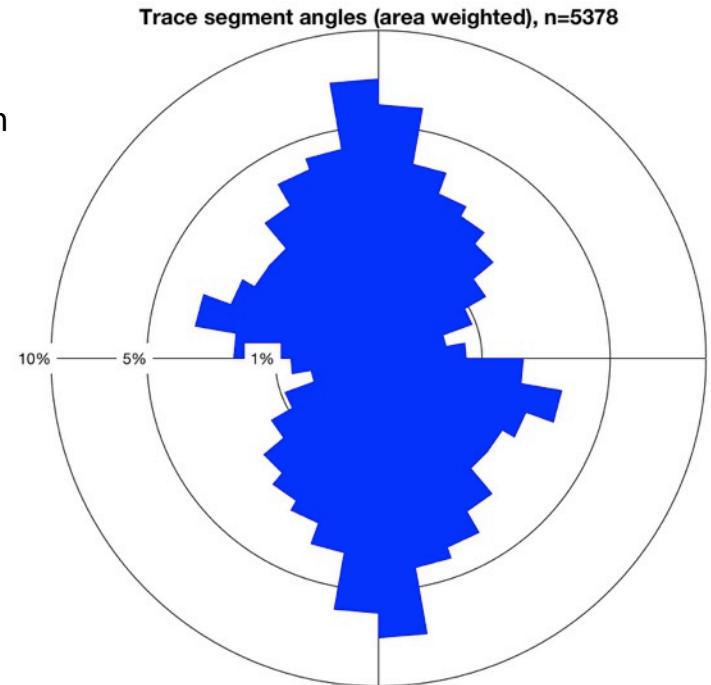
☒ Rose diagram (area-weighted)  
 Rotation of Y-axis from N (°)

☒ Cross plot lengths v angles  
 Bin size (°)



FracPaQ provides three plots of orientation data, derived from the angles of the trace segments. Segment angles are calculated with respect to the Y-axis, taking clockwise as positive. To change this in the event that the Y-axis is not aligned due North, enter a number in the text box labelled 'Rotation of Y-axis from N'. This number is then subtracted from each of the segment angles to produce a 'corrected' plot. The number of bins in the histogram and the bin size in the rose diagram can be selected with the dropdown list boxes. The rose diagram is plotted using area-weighting as this provides a more robust measure of orientation distributions in 2D (Nemec, 1988).

The plots are saved in the current folder as **FracPaQ2D\_\*angle.tif**, at a default resolution of 300 dpi. The figures are produced by the script **guiFracPaQ2Dangle.m**. Edit this script file to change any default settings, such as the plot line colour or the print file resolution.



## Fluid flow – Connectivity

Fluid flow

☒ I-Y-X connectivity

☒ Permeability ellipse

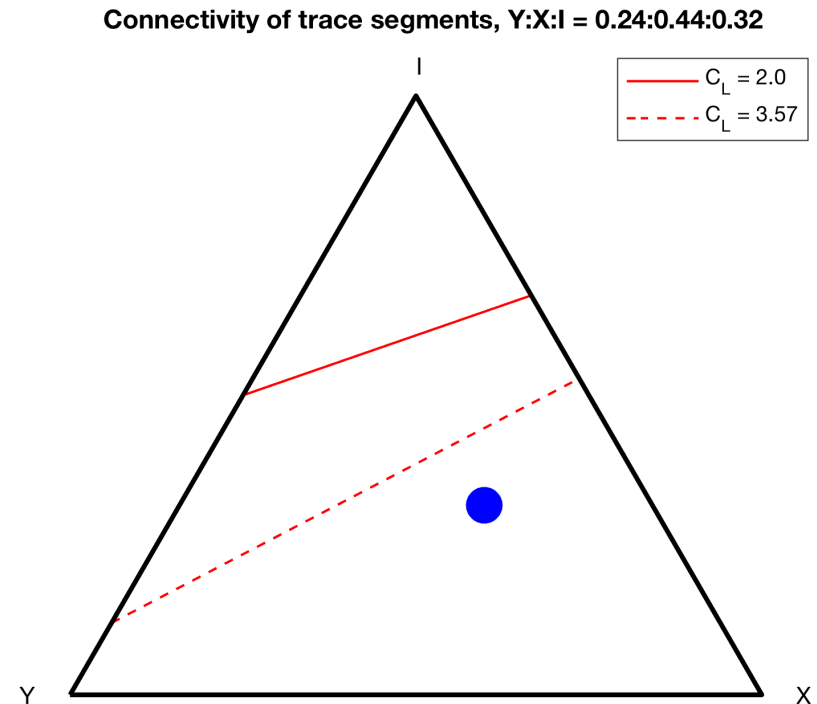
Aperture

Lamda factor

Click on the checkbox “I-Y-X connectivity” to see a ternary plot of relative proportions of I, Y and X nodes in the fracture network (Manzocchi, 2002). I nodes are the isolated ends of traces, Y nodes are splays or abutments, and X nodes are intersections.

Also shown on this plot are two contour lines for  $C_L$  – the number of connections per line (or trace in our terminology) from Sanderson & Nixon (2015). Higher values of  $C_L$  are indicative of better connectivity, although the contours depend on other attributes of the fracture network, such as the length distribution and the spatial distribution.

Better connected networks tend to plot towards the bottom of this diagram (higher proportions of Y and X nodes).



The figure is saved in the current folder as **FracPaQ2D\_IYXtriangle.tif**, at a default resolution of 300 dpi. The figures are produced by the script **guiFracPaQ2Dpattern.m**. Edit this script file to change any default settings, such as the colour or the print file resolution.



## Fluid flow – Permeability

Fluid flow

☒ I-Y-X connectivity

☒ Permeability ellipse

Aperture

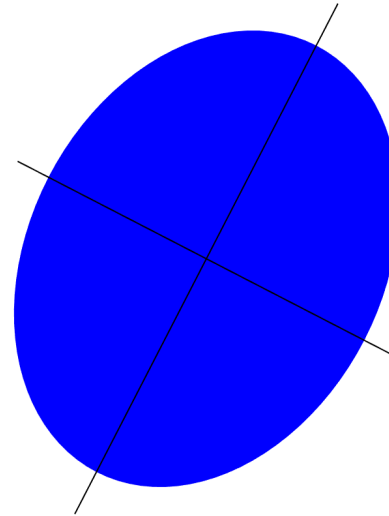
Lamda factor

Click on the checkbox “Permeability ellipse” to see the 2D permeability ellipse for the fracture network. This estimate is produced from a combination of lengths, orientations and spatial densities using the tensorial method of Suzuki et al. (1998).

The long axis of the ellipse is the principal permeability direction ( $\mathbf{k}_1$ ), and the short axis is the minimum permeability direction ( $\mathbf{k}_2$ ).

The user can make changes to the “Aperture” parameter (default is 1, pixels or metres) and the “Lambda factor”, which is a coefficient satisfying the inequality . If all fractures are fully connected, can be set to 1 (Suzuki et al., 1998). The user can adjust this variable based on the results obtained from the connectivity plot.

Permeability,  $k_1:k_2=1:1$ ,  $k_1$  azimuth=022



The figure is saved in the current folder as **FracPaQ2D\_permtensor.tif**, at a default resolution of 300 dpi. The figures are produced by the script **guiFracPaQ2Dtensor.m**. Edit this script file to change any default settings, such as the colour or the print file resolution.

## Permeability Tensor Ellipse

Fluid flow

☒ I-Y-X connectivity

☒ Permeability ellipse

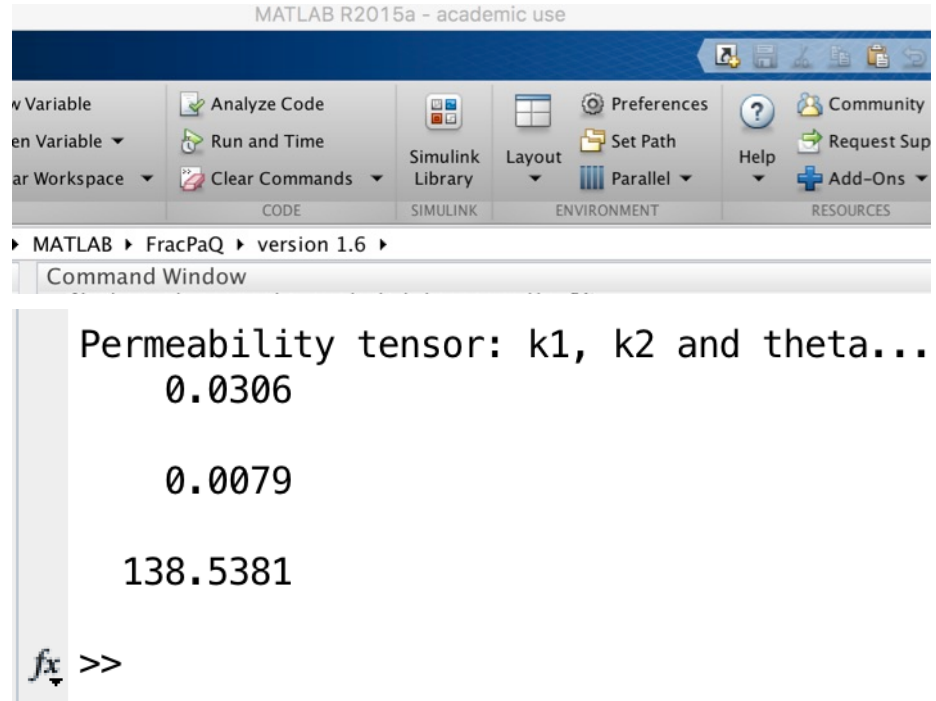
Aperture

Lamda factor

The permeability ellipse is supplemented with text outputs in the MATLAB™ Command Window.

The numerical values of  $k_1$  (maximum),  $k_2$  (minimum), and the azimuth of  $k_1$  (**theta**, in degrees measured from the Y-axis), are printed in the Command Window.

The units of  $k$  default to pixels<sup>2</sup>, unless a Scaling Factor (pixels/metre) has been entered on the left hand side of the main window, in which case the units are metres<sup>2</sup>.



```

MATLAB R2015a - academic use
v Variable      Analyze Code  Simulink Library  Layout  Preferences  ?  Community
en Variable    Run and Time  Clear Commands   Parallel  Set Path     Help  Request Sup
ar Workspace   CODE          SIMULINK          ENVIRONMENT  RESOURCES

MATLAB > FracPaQ > version 1.6 >
Command Window

Permeability tensor: k1, k2 and theta...
    0.0306

    0.0079

    138.5381

fx >>
  
```

# Bibliography

Bonnet, E., Bour, O., Odling, N.E., Davy, P., Main, I., Cowie, P. & Berkowitz, B. (2001). Scaling of fracture systems in geological media. *Reviews of geophysics*, 39(3), pp.347-383.

Clauset, A., Shalizi, C. R. & Newman, M. E. J. (2009). Power-law distributions in empirical data. *SIAM Review*, 51(4), 661.

Dershowitz, W.S. & Herda, H.H. (1992). Interpretation of fracture spacing and intensity. In: The 33th US Symposium on Rock Mechanics (USRMS). American Rock Mechanics Association.

**Farrell, N.J.C.** (2015). Unpublished PhD thesis. University of Aberdeen.

Gillespie, P.A., Howard, C.B., Walsh, J.J. & Watterson, J. (1993). Measurement and characterisation of spatial distributions of fractures. *Tectonophysics*, 226(1-4), pp.113-141.

**Healy, D., Rizzo, R.E., Cornwell, D.C., Farrell, N.J.C., Watkins, H., Timms, N.E., Gomez-Rivas, E. & Smith, M.** (in review). FracPaQ: a MATLAB™ toolbox for the quantification of fracture patterns.

Manzocchi, T. (2002). The connectivity of two-dimensional networks of spatially correlated fractures. *Water Resources Research*, 38(9).

Mauldon, M., Dunne, W.M. & Rohrbaugh, M.B. (2001). Circular scanlines and circular windows: new tools for characterizing the geometry of fracture traces. *Journal of Structural Geology*, 23(2), pp.247-258.

Nemec, W. (1988). The shape of the rose. *Sedimentary Geology*, 59(1-2), pp.149-152.

Newman, M. E. J. (2005). Power laws, Pareto distributions and Zipf's law. *Contemporary Physics*, 46(5), 323–351.

**Rizzo, R.E., Healy, D. & De Siena, L.** (in review). The Benefits of a Maximum Likelihood Estimator.

Sanderson, D.J. & Nixon, C.W. (2015). The use of topology in fracture network characterization. *Journal of Structural Geology*, 72, pp.55-66.

**Smith, M.** (2016). Unpublished MSc thesis. University of Aberdeen.

Suzuki, K., Oda, M., Yamazaki, M. & Kuwahara, T. (1998). Permeability changes in granite with crack growth during immersion in hot water. *International Journal of Rock Mechanics and Mining Sciences*, 35(7), pp.907-921.

**Watkins, H.** (2015). Unpublished PhD thesis. University of Aberdeen.

## Acknowledgements

`lineSegmentIntersect.m` written by U. Murat Erdem; available on Mathworks FileExchange:

<http://uk.mathworks.com/matlabcentral/fileexchange/27205-fast-line-segment-intersection>

`readtext.m` written by Peder Axensten; available on Mathworks FileExchange:

<http://uk.mathworks.com/matlabcentral/fileexchange/10946-readtext>