

Quantification of Fracture Attributes from Terrestrial Laser Scanning – Improving Input Parameters for Discrete Fracture Network (DFN) Modelling*

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Abstract

Fluid flow in fractured reservoirs is strongly controlled by the connectivity and extent of the fracture network. Information on the fracture network in a hydrocarbon or geothermal reservoir is typically inferred from seismic and borehole data. An additional source of information can be outcrops like quarries or tunnels, provided they belong to the same tectonostratigraphic unit as the subsurface reservoir. Such reservoir analogues can provide comprehensive insights into the geometry and spatial distribution of the fracture network and allow building a large database of fracture attributes. This information can be used to set up a Discrete Fracture Network model (DFN) from which fundamental hydraulic properties of the reservoir can be derived. Terrestrial laser scanning (TLS) is a well-established method for outcrop analysis. In comparison to traditional geological survey techniques, laser scanning allows for a faster and more efficient collection of fracture attributes. Important input parameters for the DFN model are the distribution functions for the orientation and size of the fractures as well as the fracture density. These data can be extracted from the three-dimensional model of the outcrop obtained from TLS. After preprocessing of the point cloud, including registration of the point clouds and removal of artifacts and vegetation, homogeneously distributed normal vectors on surfaces within the model are calculated. Afterwards, individual fracture sets are identified using a cluster analysis or a visual differentiation by the interpreter directly in the model. Patches automatically created from the point cloud allow for determination of fracture density for each set by identifying the number of intersections of an arbitrary path through the point cloud. The shape of these patches is chosen as ellipses to represent natural fracture geometries. The resulting values are expressed in terms of a one dimensional intensity value (P10) and converted to a volumetric intensity (P32). Finally, the geometry and size of the fractures are analyzed through vertices of created patches/polygons on the surface. A best fitting distribution function for the size, most commonly the length of the fracture, is inferred mathematically. This semi-automatic method of fracture parameter extraction based on TLS creates a much larger database than traditional methods and therefore substantially increases the statistical significance of the input parameters for DFN modelling.

Quantification of Fracture Attributes from Terrestrial Laser Scanning –

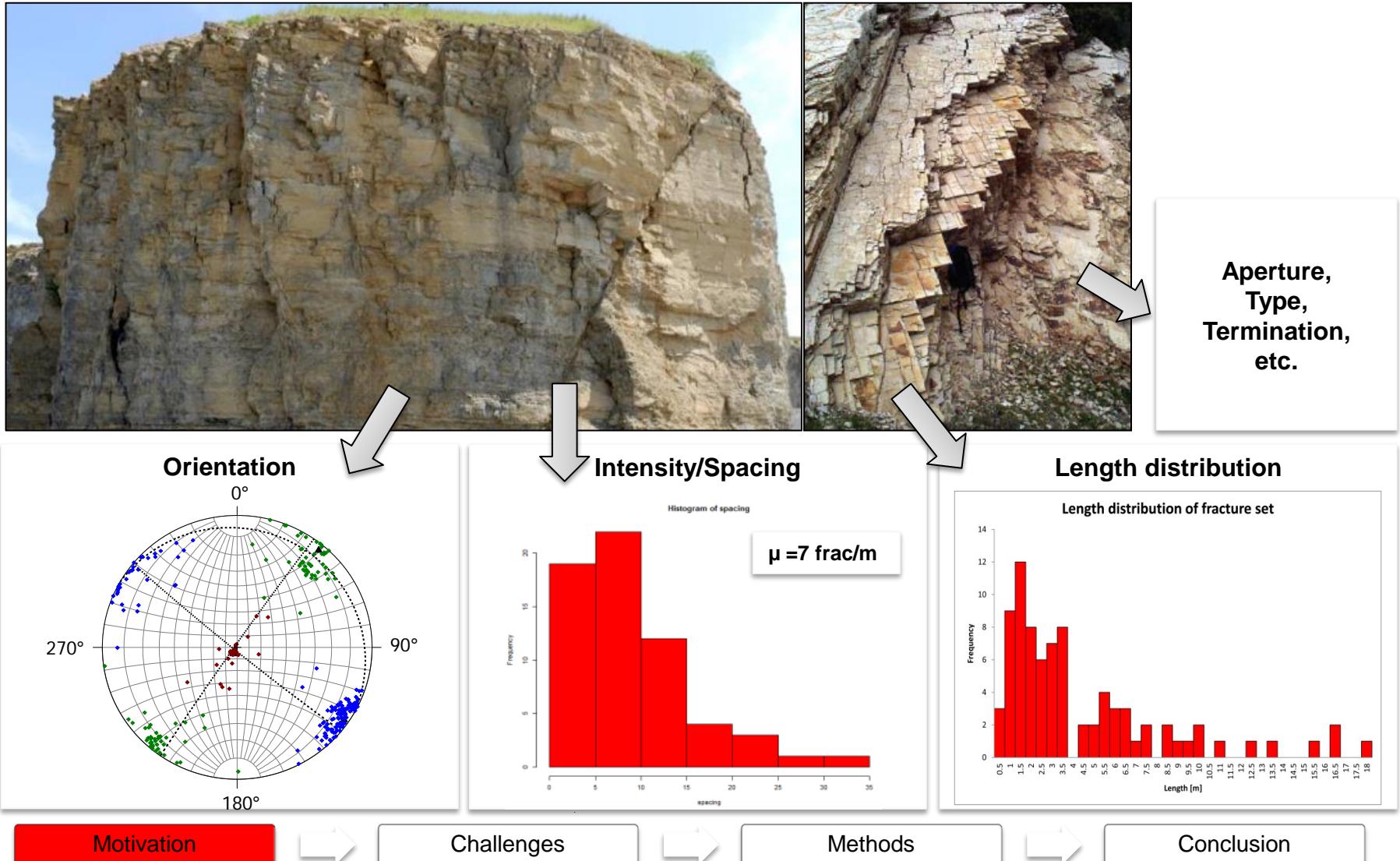
Improving Input Parameters
for Discrete Fracture Network (DFN) Modelling



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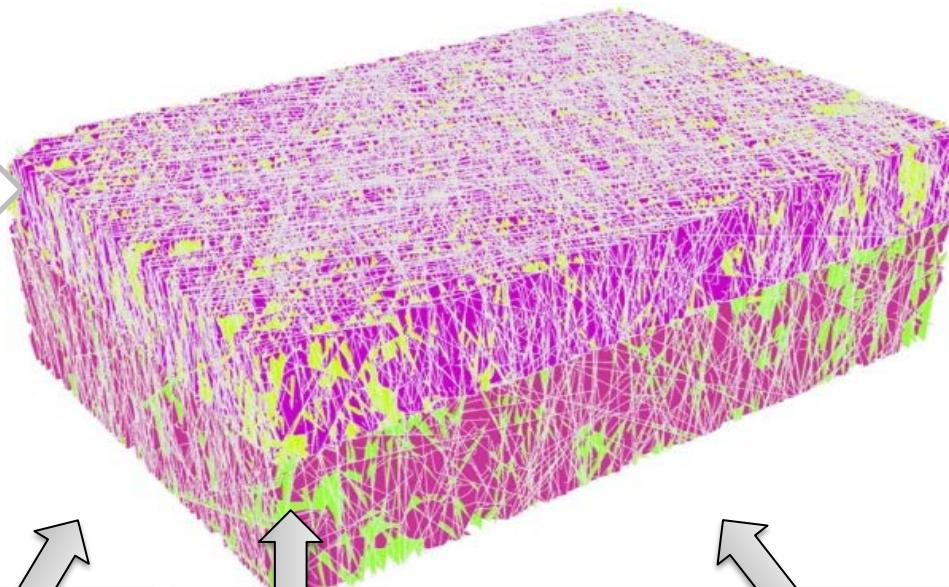
laux@geo.tu-darmstadt.de

Fracture Characterization



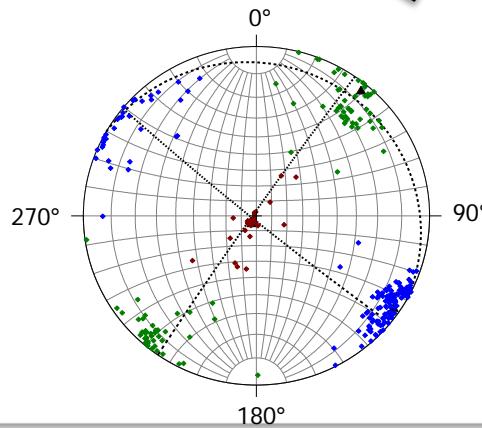
Discrete Fracture Network (DFN)-Model

- Representing fracture network
- Describes fluid flow behaviour

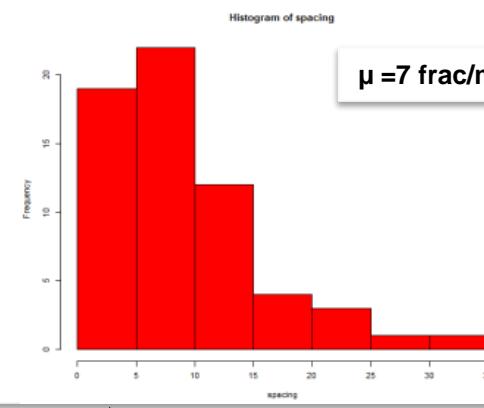


Aperture,
Type,
Termination,
etc.

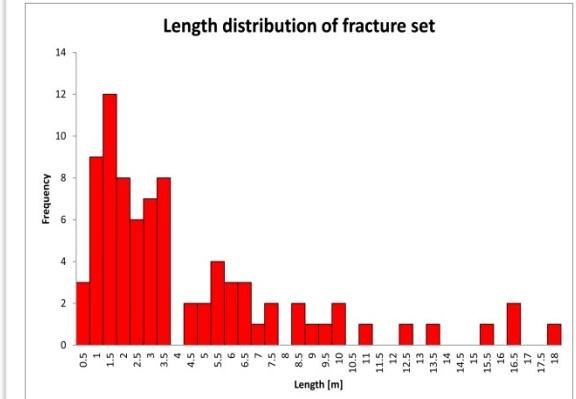
Orientation



Intensity/Spacing



Length distribution



Motivation

Challenges

Methods

Conclusion

Data acquisition

Traditional Methods



Terrestrial Laser Scanning (TLS)



Motivation

Challenges

Methods

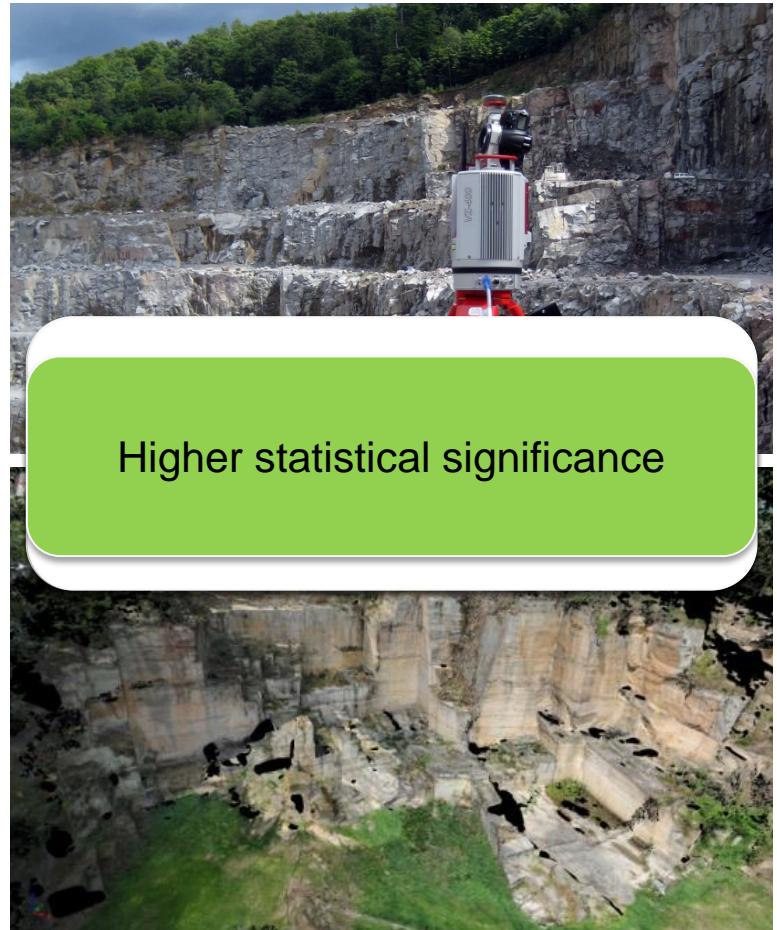
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Data acquisition

Traditional Methods



Terrestrial Laser Scanning (TLS)



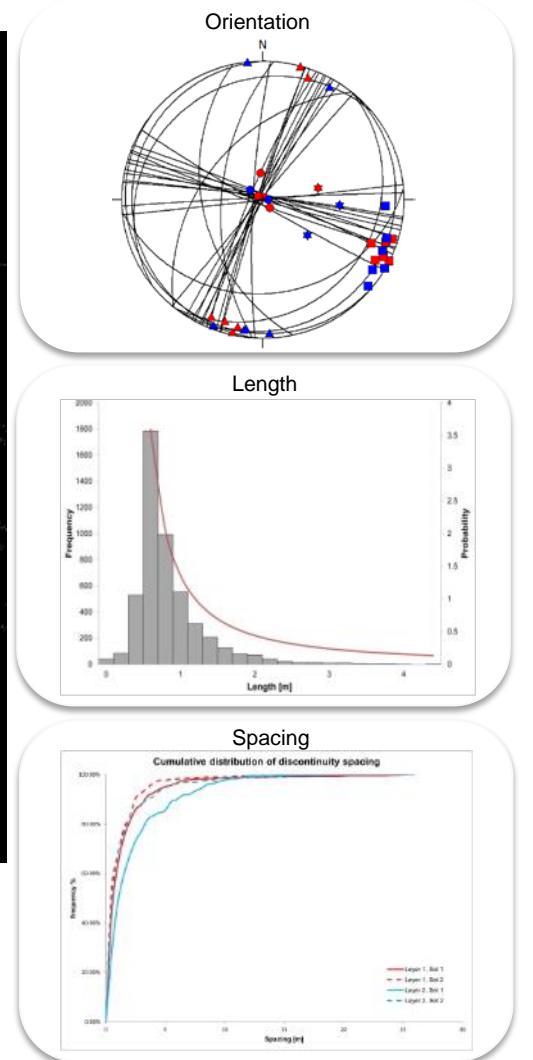
Motivation

Challenges

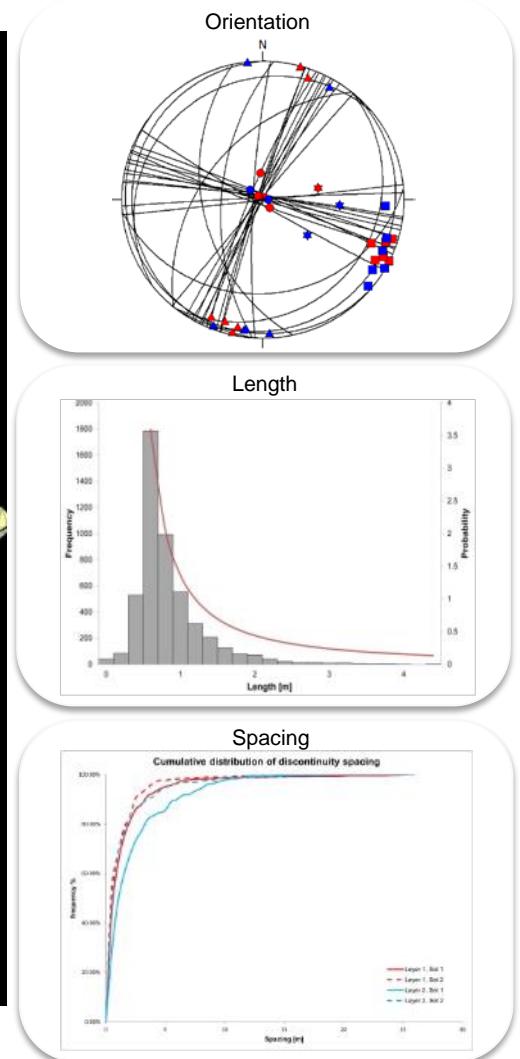
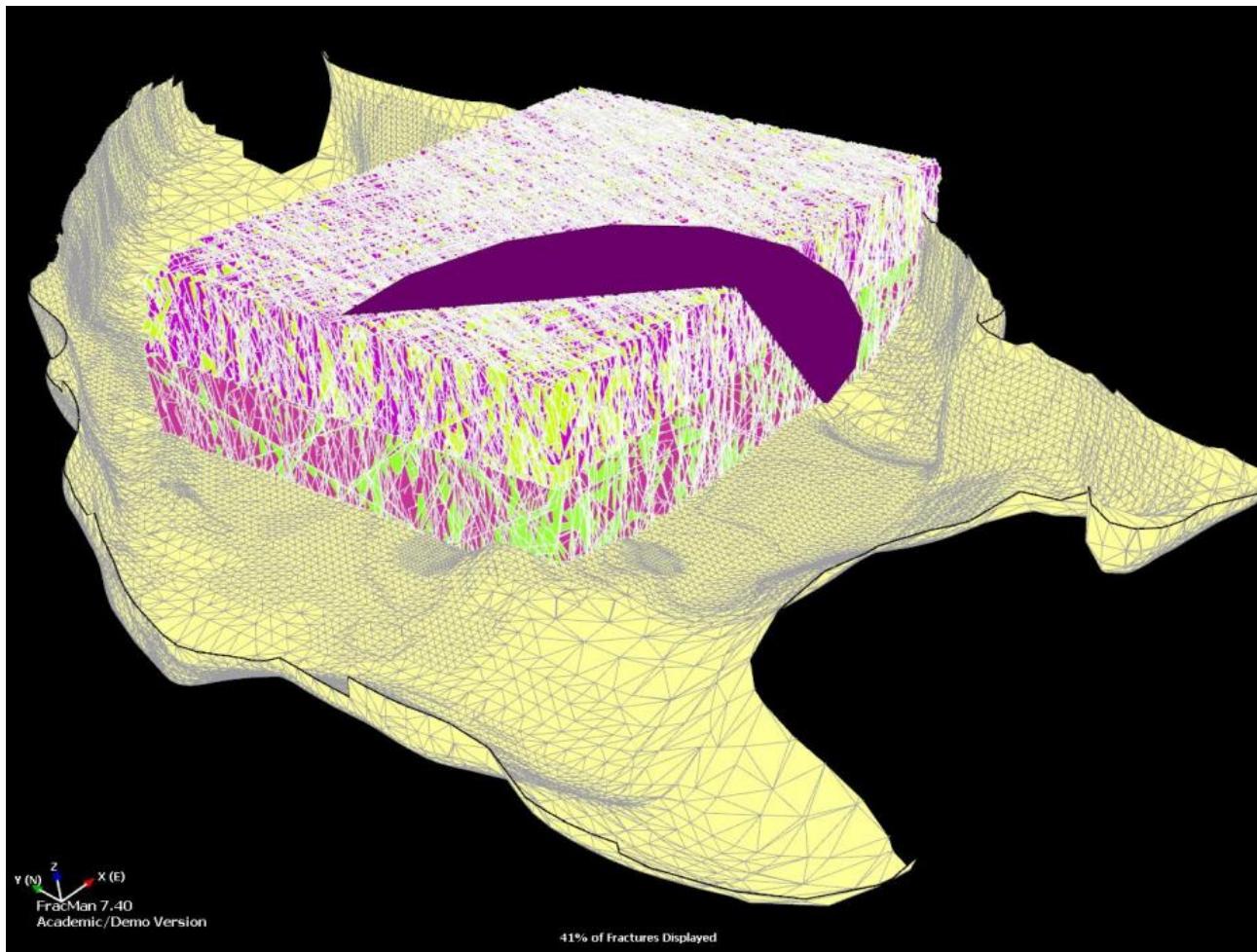
Methods

Conclusion

Outcrop analysis with TLS



Outcrop analysis with TLS



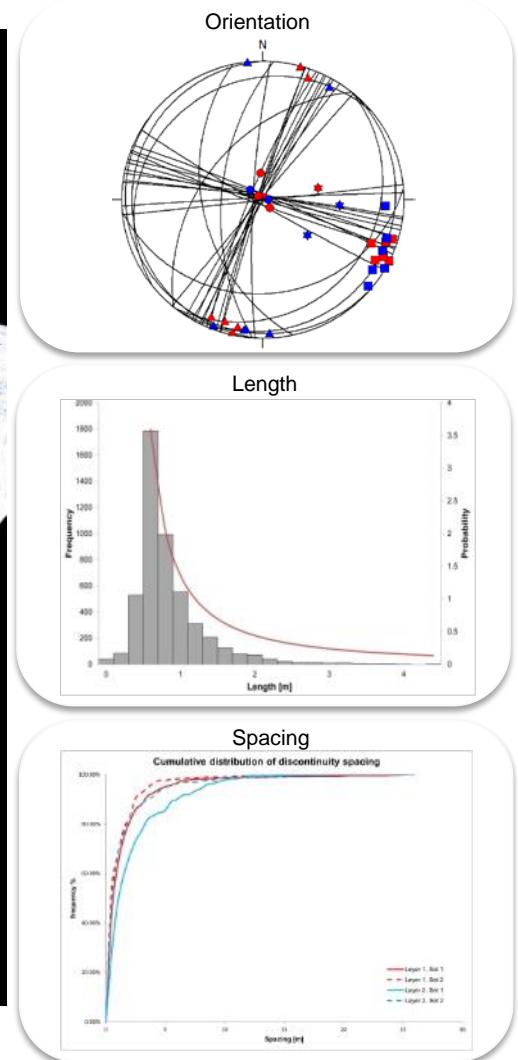
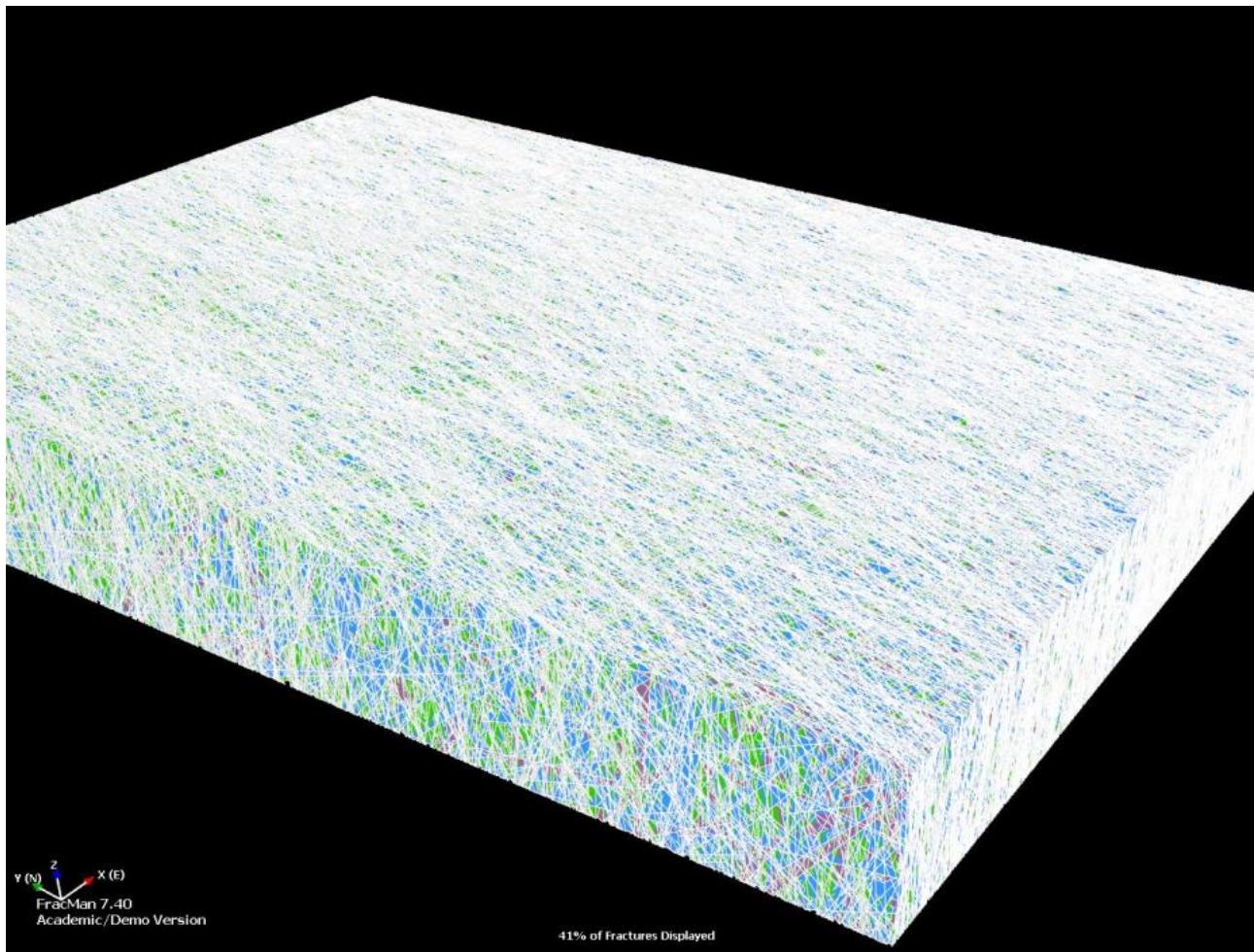
Motivation

Challenges

Methods

Conclusion

Outcrop analysis with TLS



Motivation

Challenges

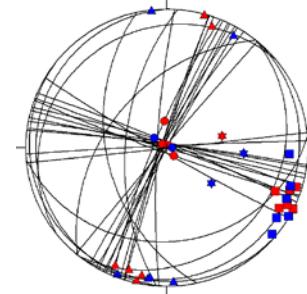
Methods

Conclusion

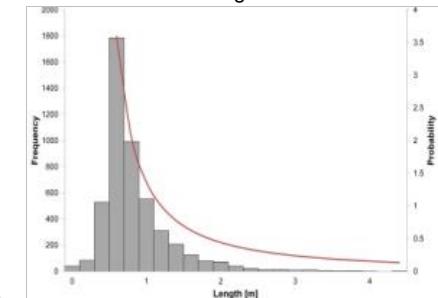
Challenges



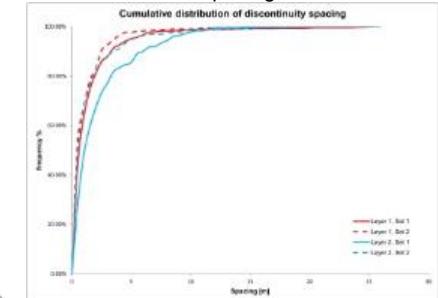
Orientation



Length



Spacing



How do we automate these methods?

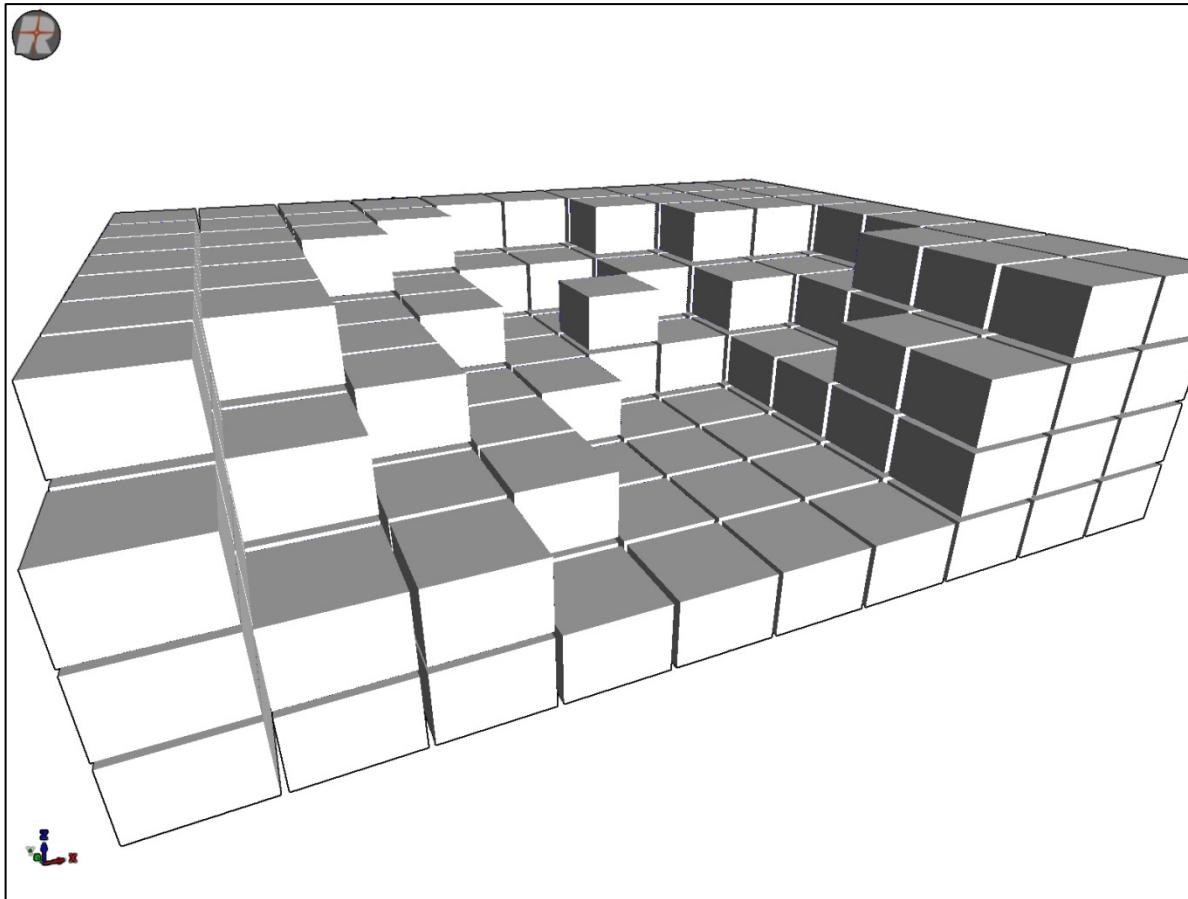
Motivation

Challenges

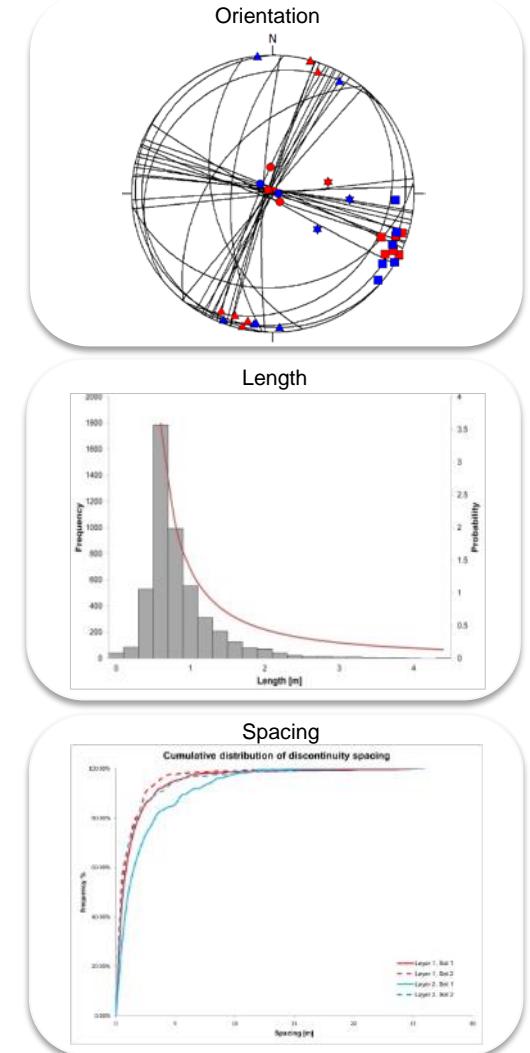
Methods

Conclusion

Methods



Hypothetical & simplified outcrop structure



Motivation



Challenges

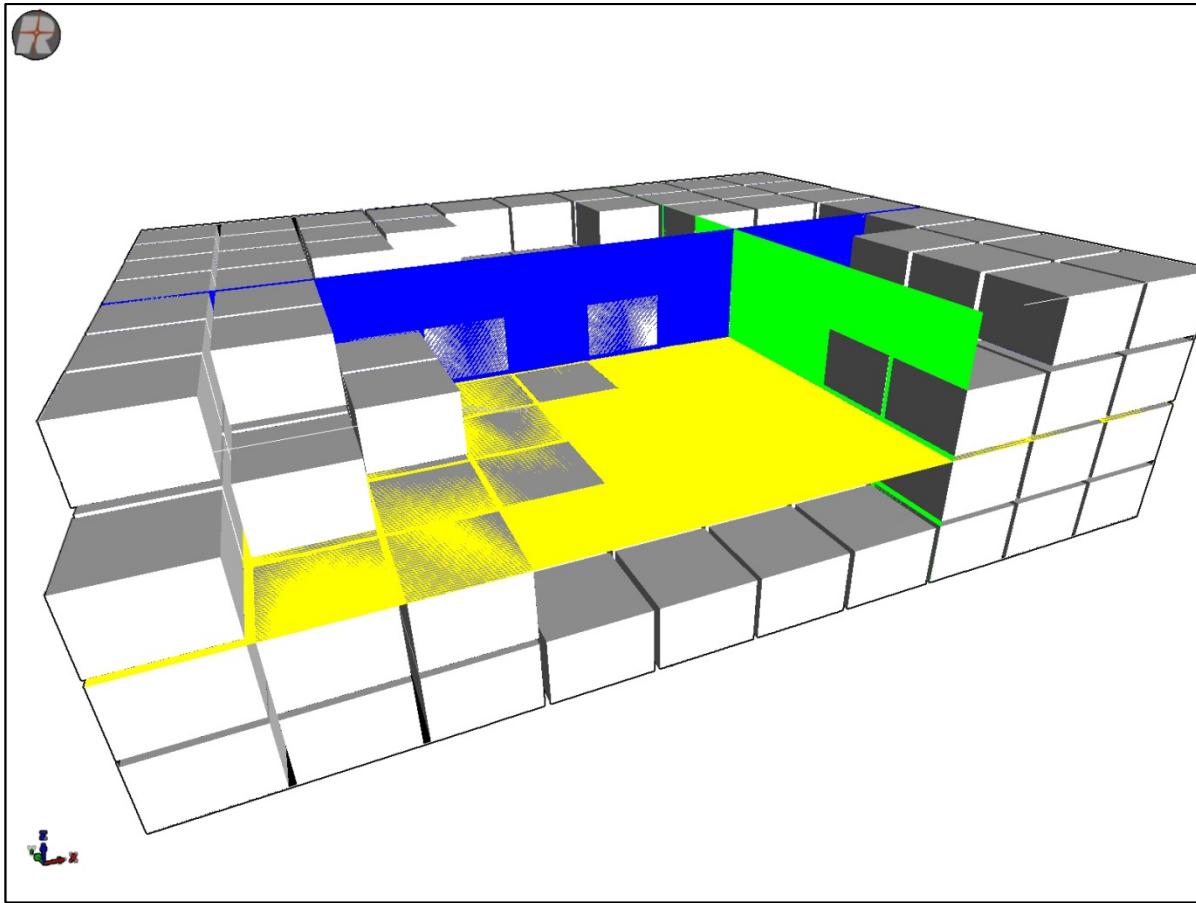


Methods

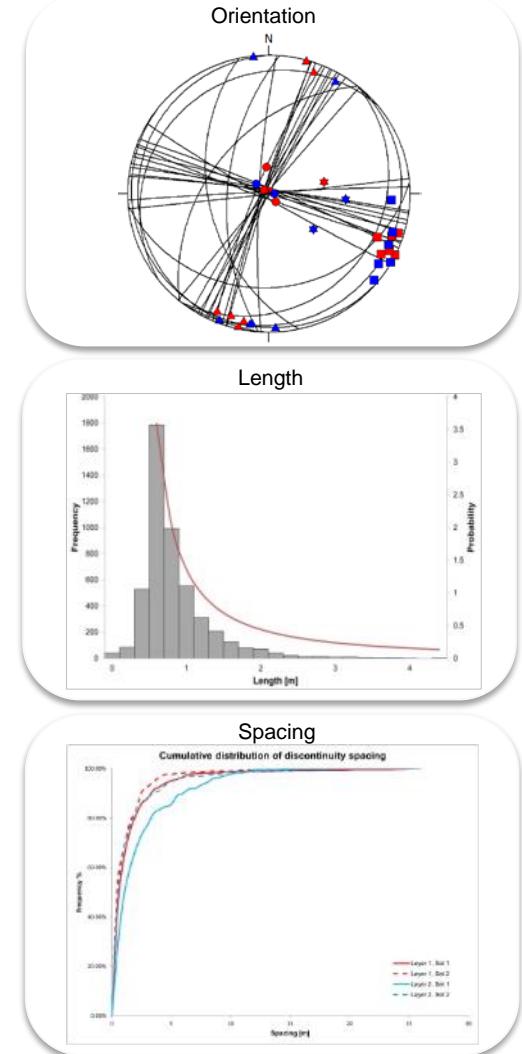


Conclusion

Methods



Three interconnected fracture sets



Motivation



Challenges

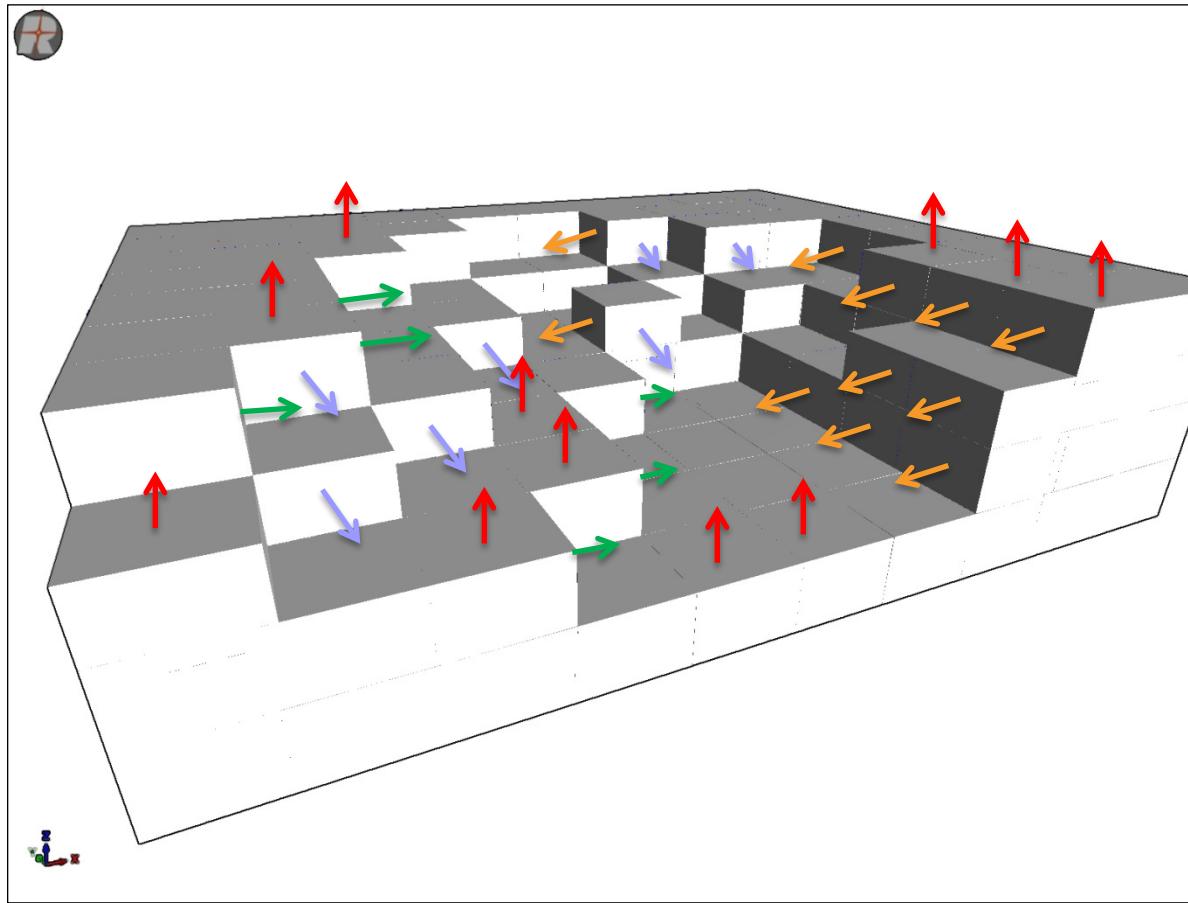


Methods

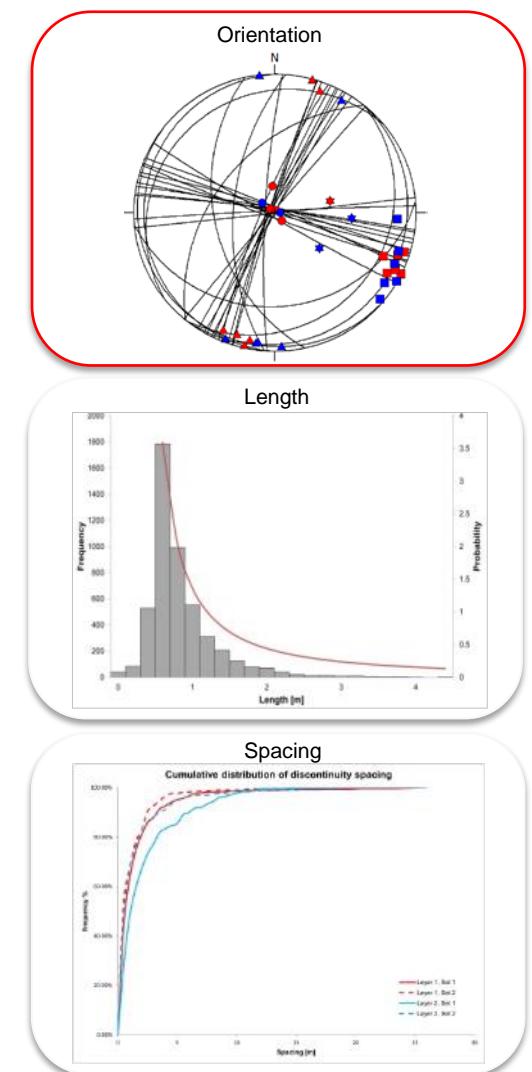


Conclusion

Methods - Orientation



Calculating Normal Vectors



Motivation



Challenges

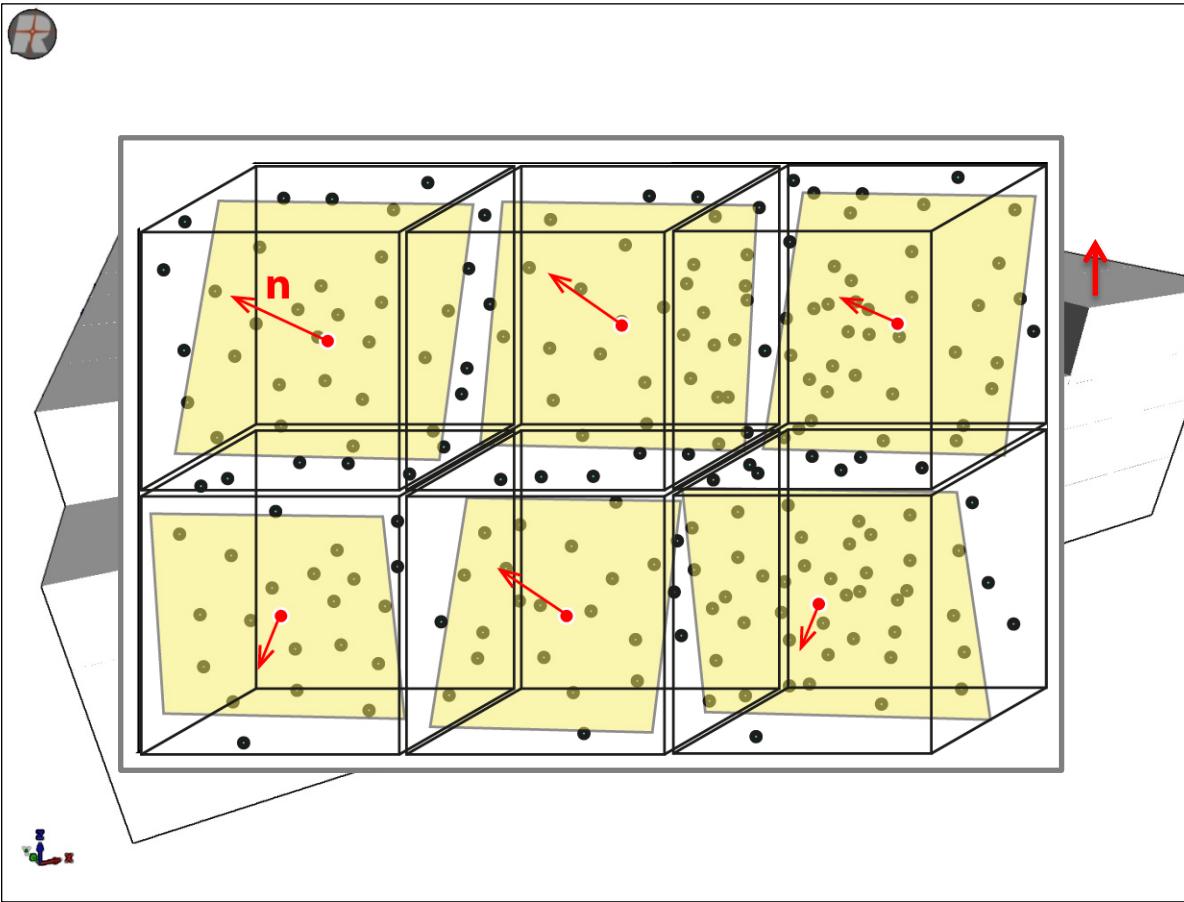


Methods

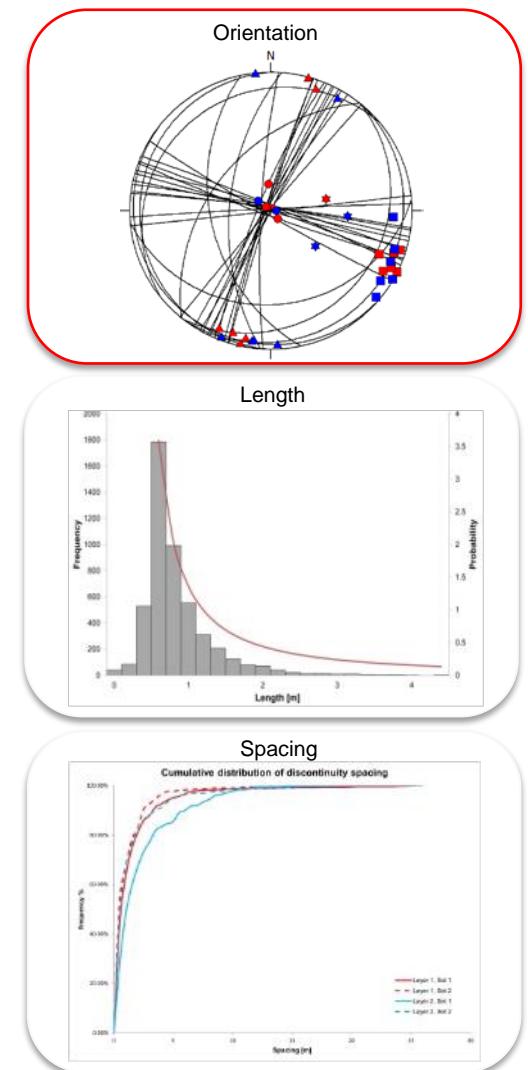


Conclusion

Methods - Orientation



Orientation measurements



Motivation



Challenges

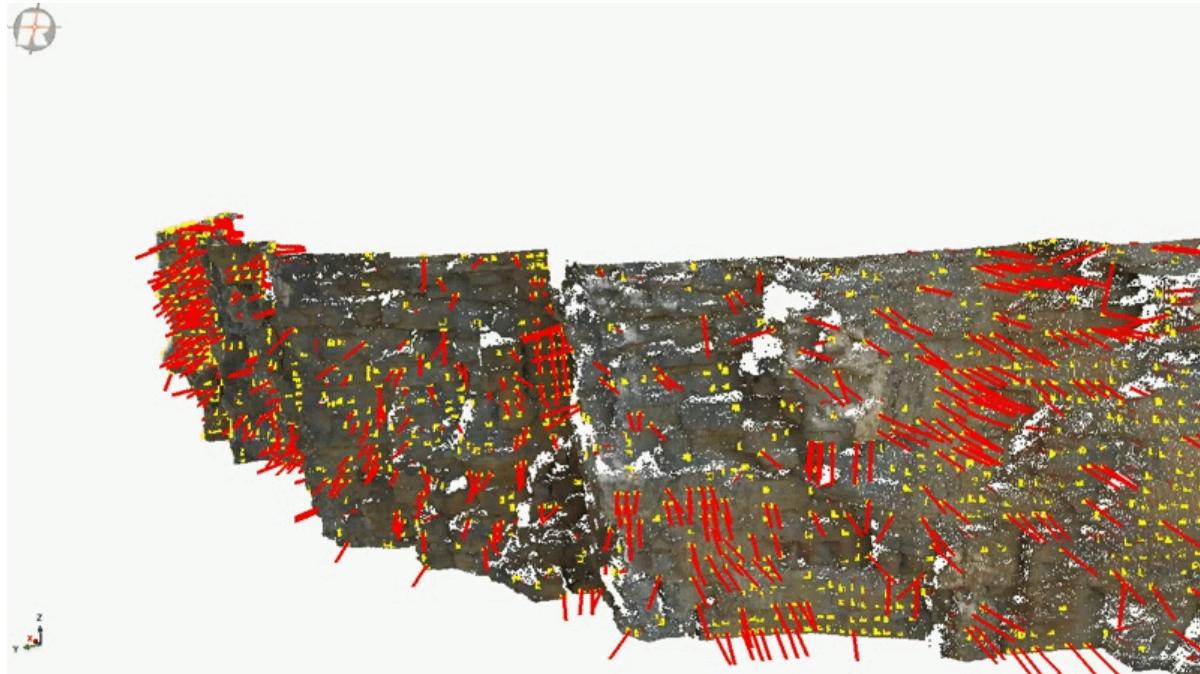


Methods

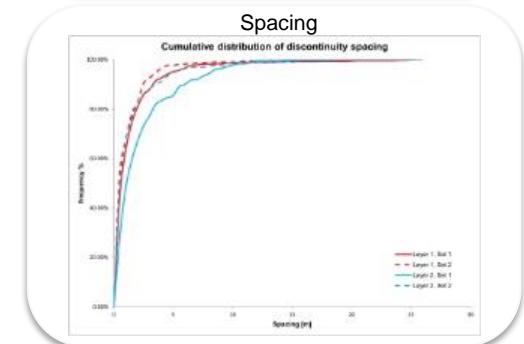
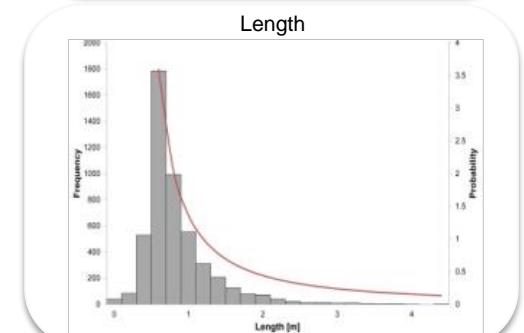
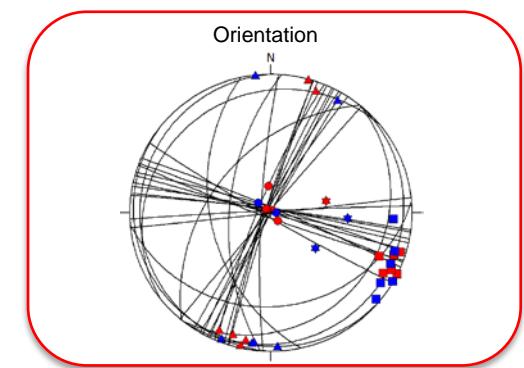


Conclusion

Methods - Orientation



Example outcrop



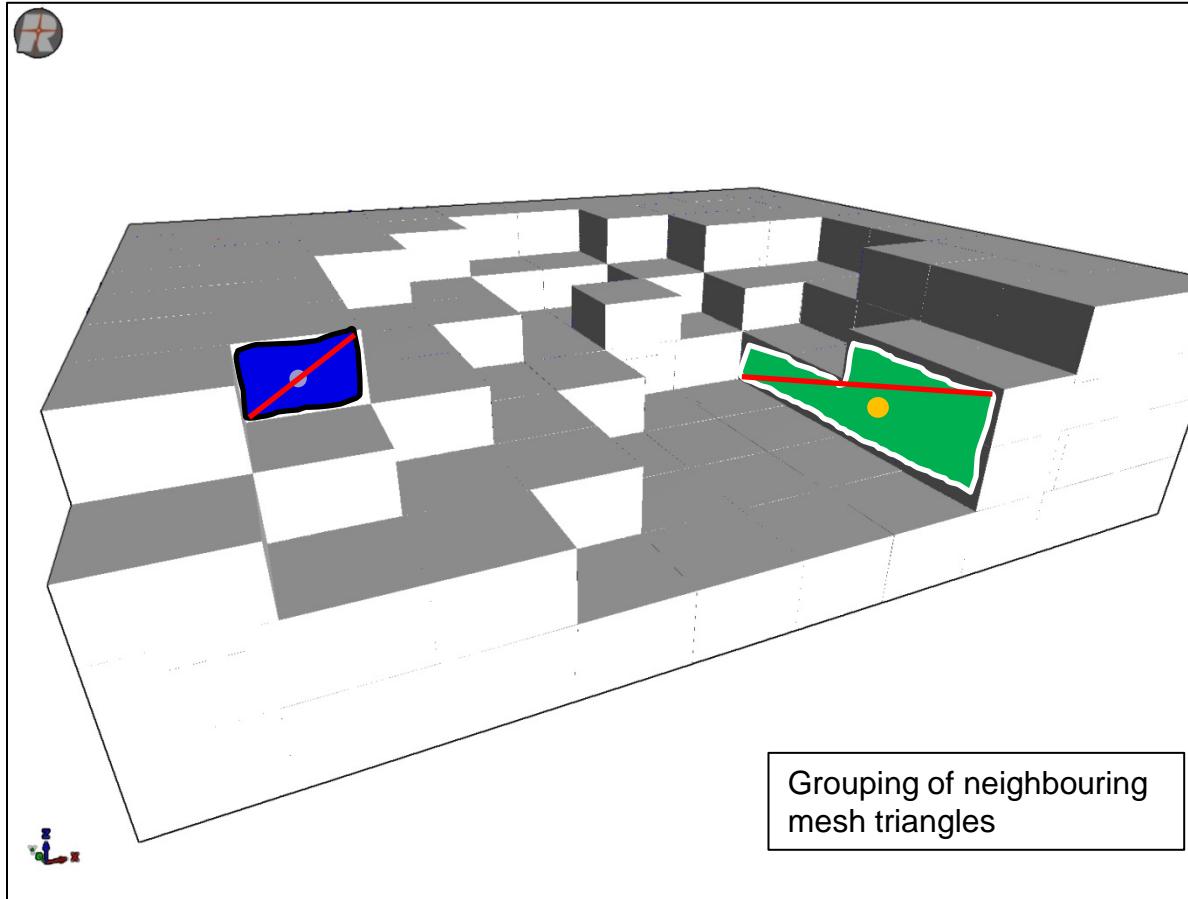
Motivation

Challenges

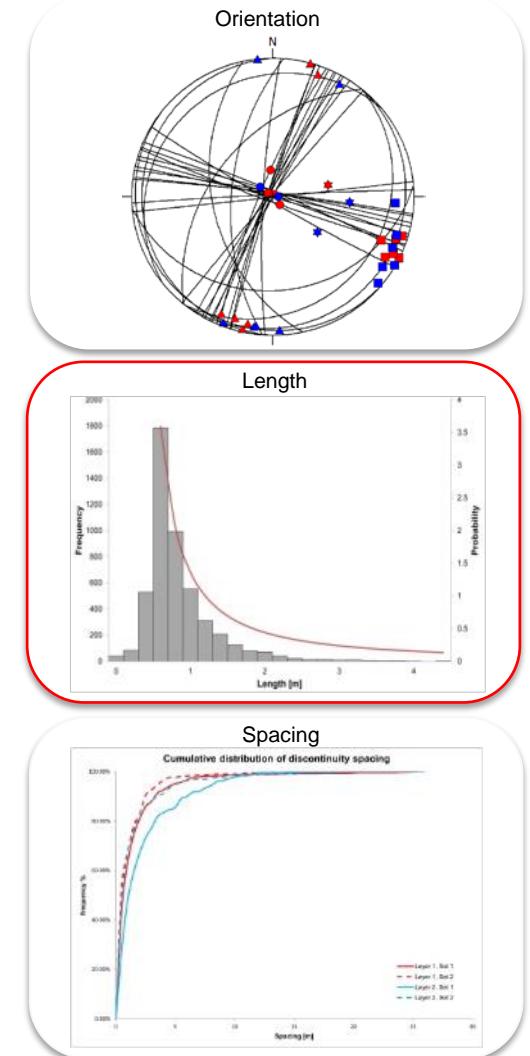
Methods

Conclusion

Methods - Length



Length measurements



Motivation



Challenges

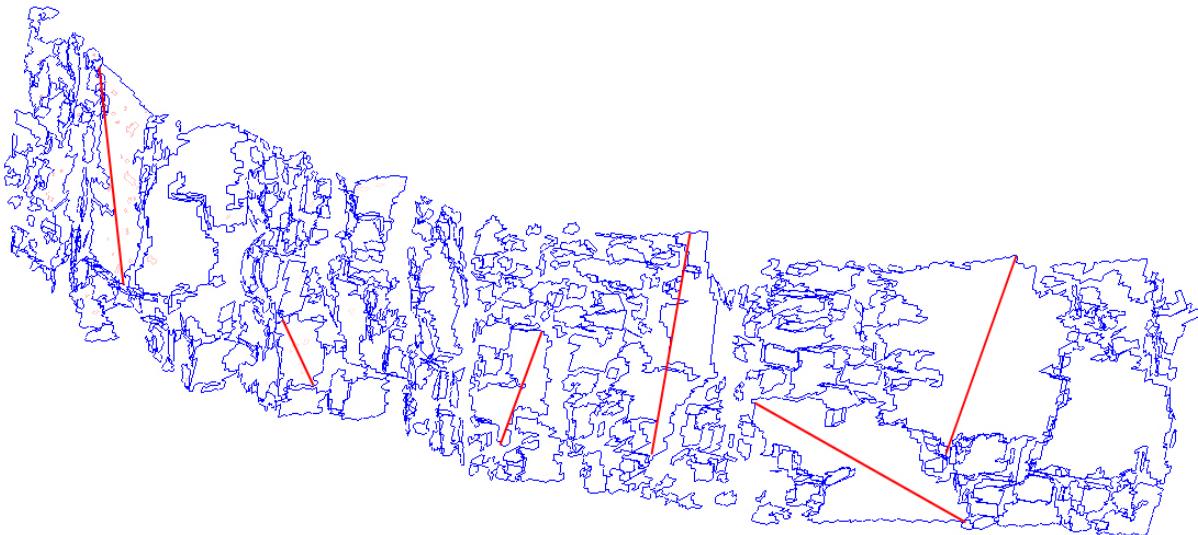


Methods

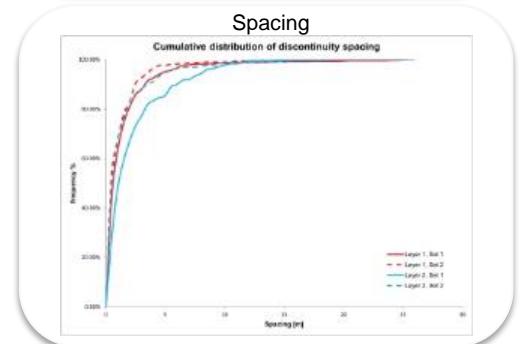
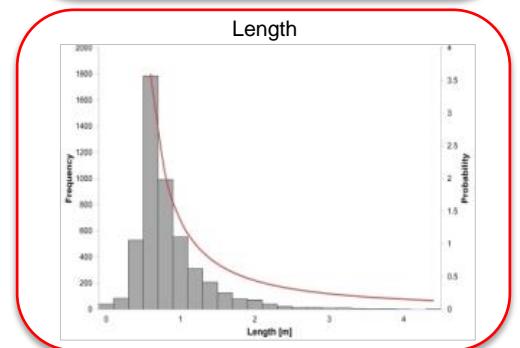
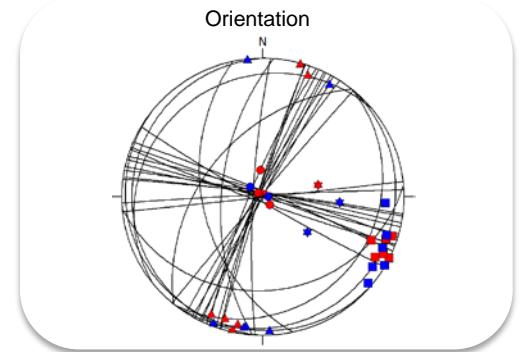


Conclusion

Methods - Length



Example outcrop



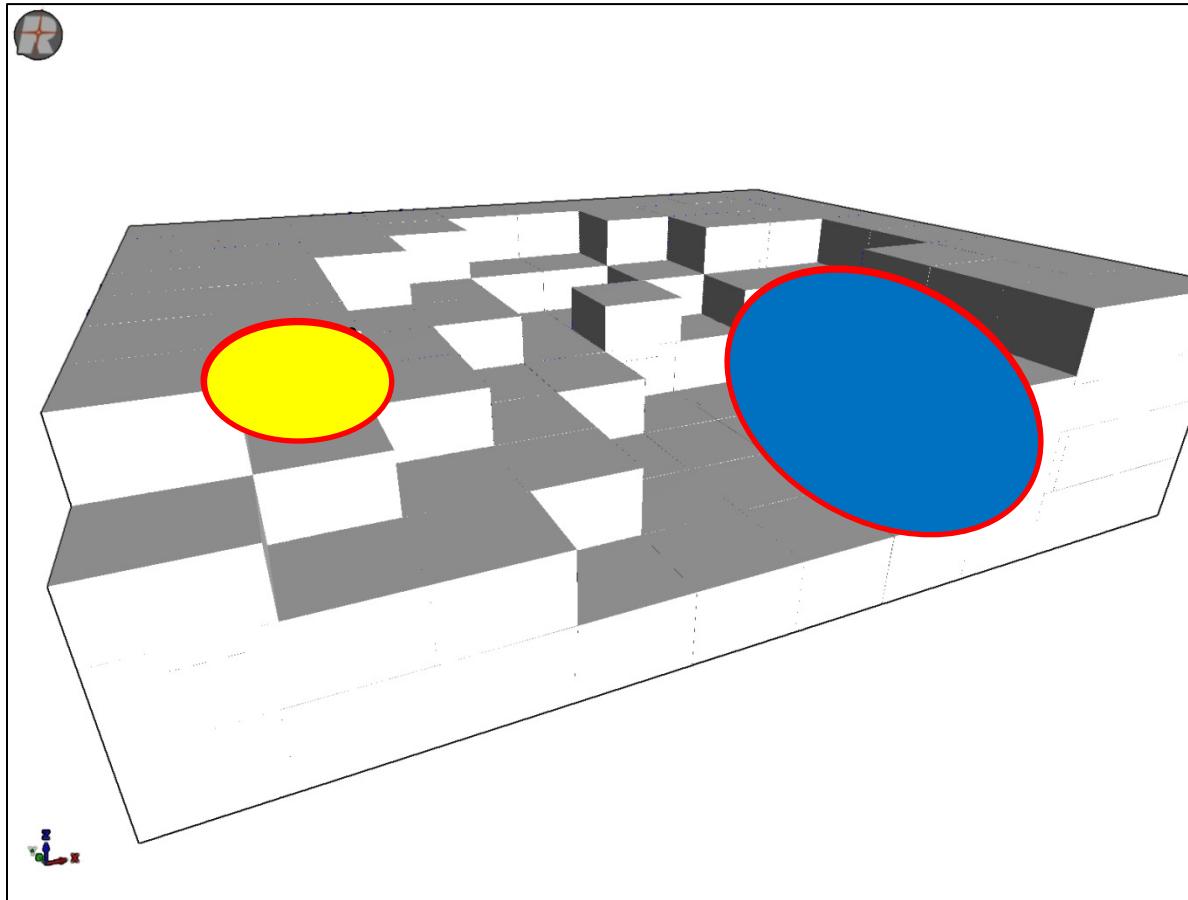
Motivation

Challenges

Methods

Conclusion

Methods - Spacing



Intensity/spacing calculations

Motivation



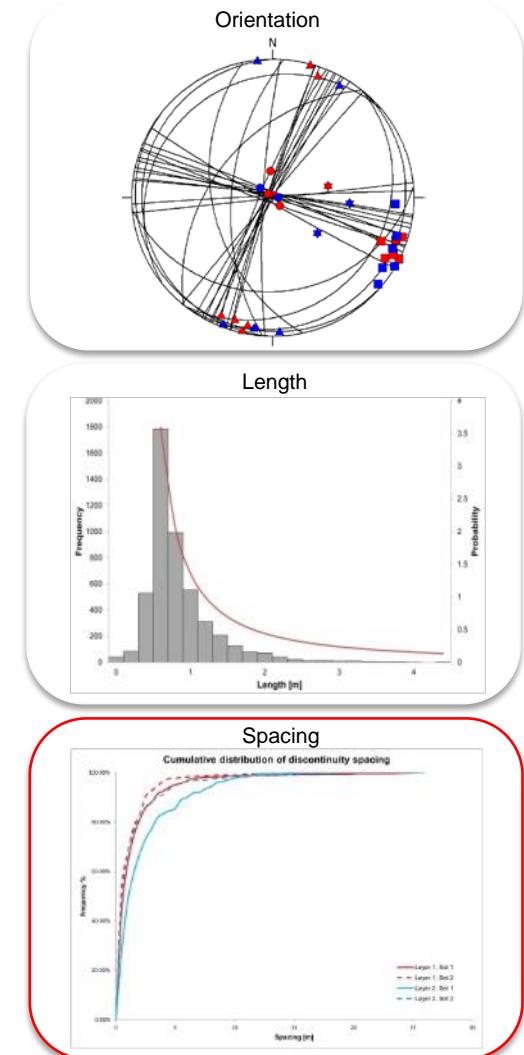
Challenges



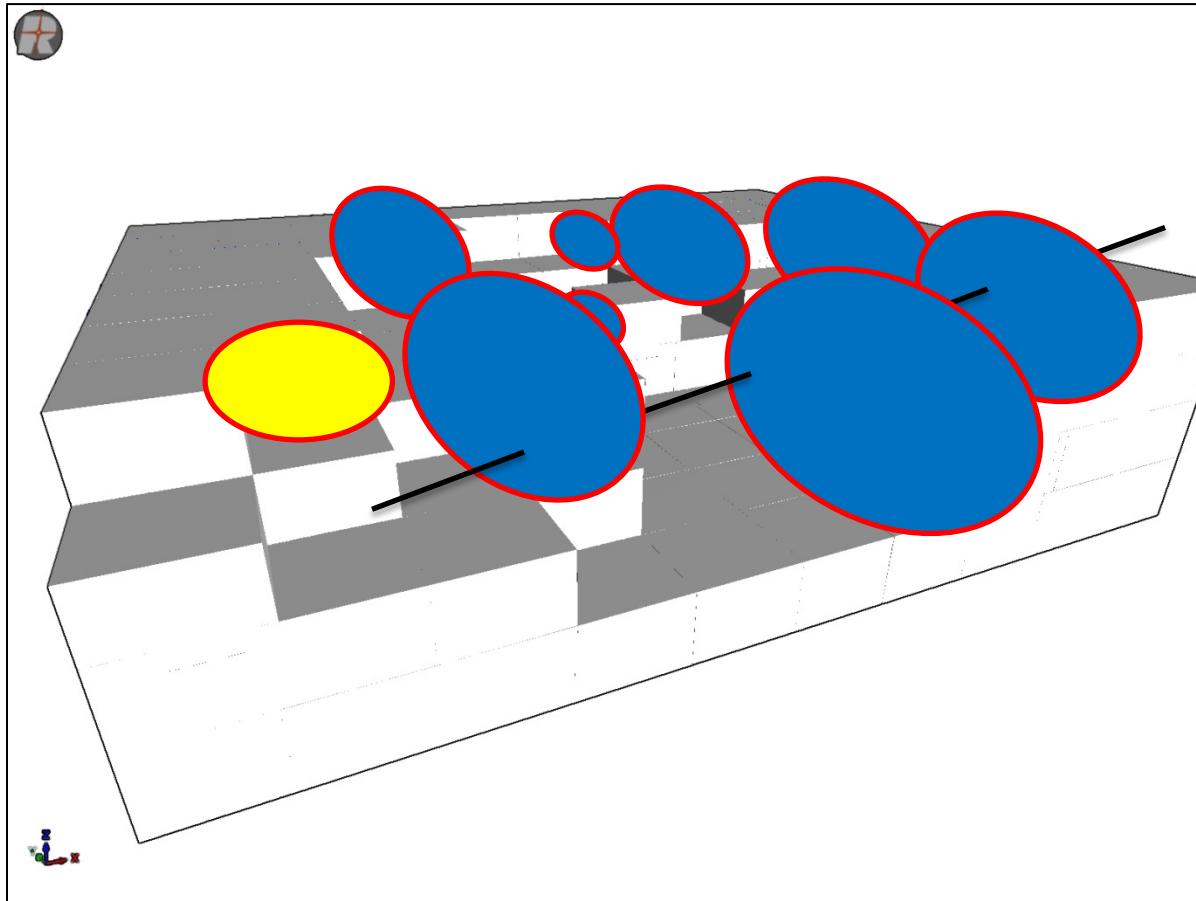
Methods



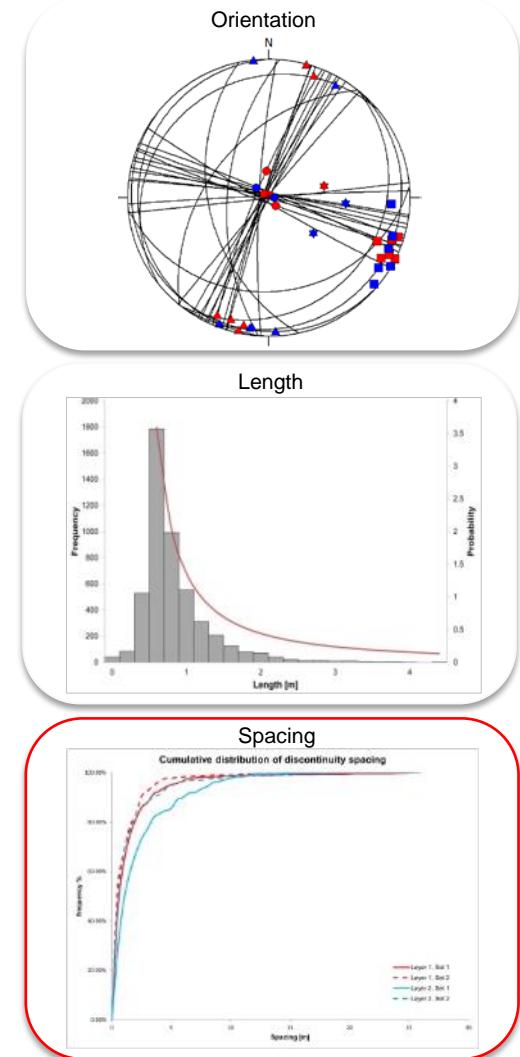
Conclusion



Methods - Spacing



Ellipses of a single fracture set



Motivation



Challenges

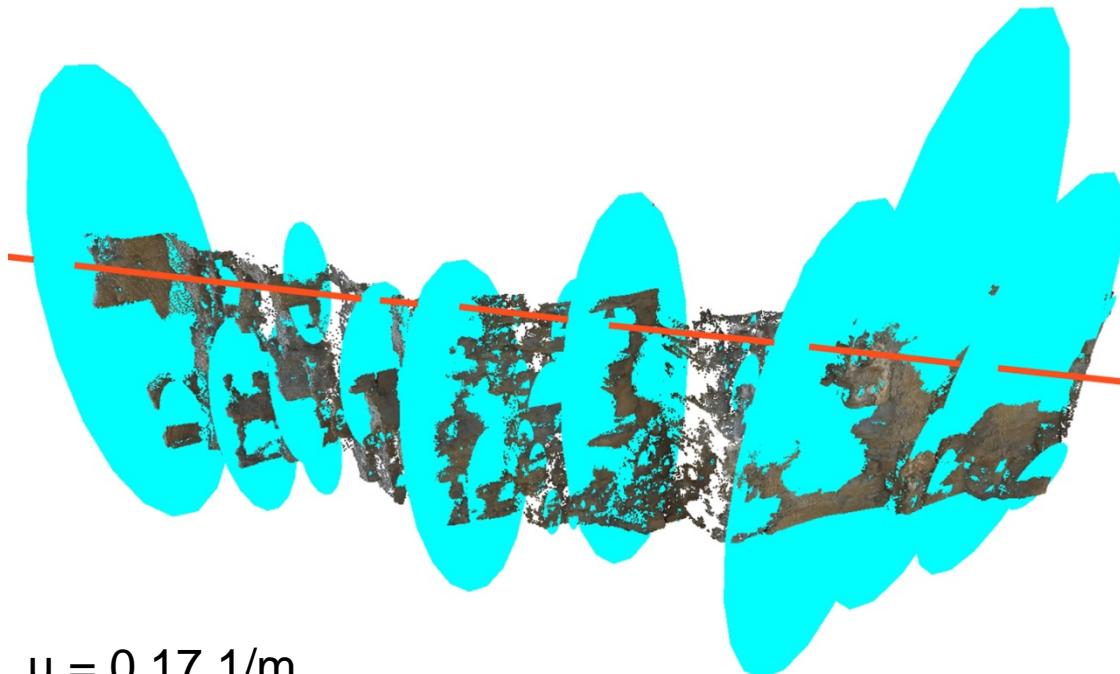


Methods



Conclusion

Methods - Spacing



$$\mu = 0.17 \text{ 1/m}$$



Example outcrop

Motivation



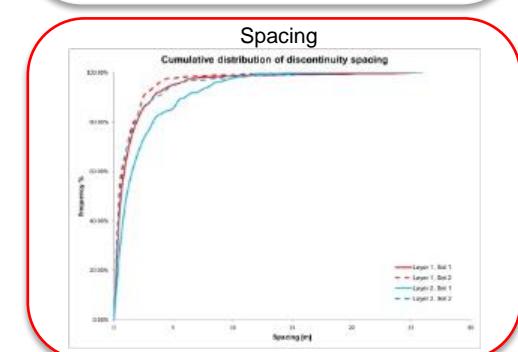
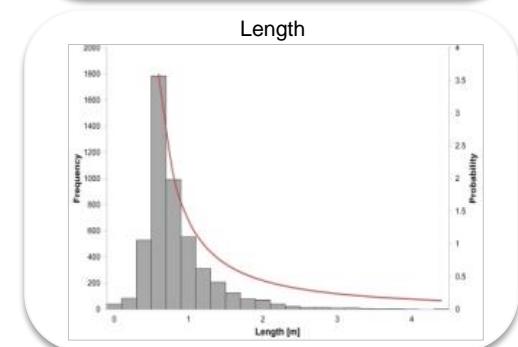
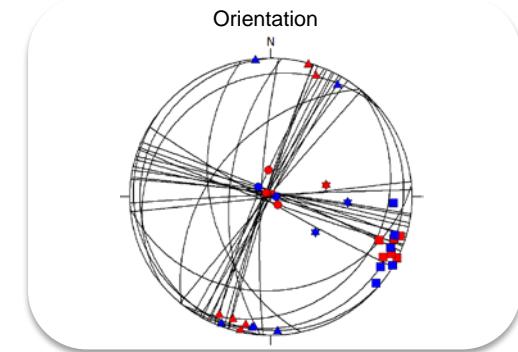
Challenges



Methods



Conclusion



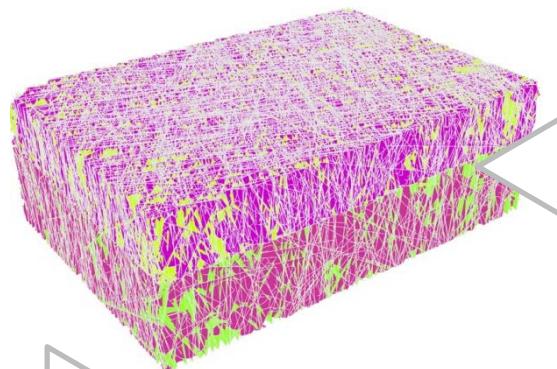
Benefits of TLS

Fracture analysis

- (Semi-)Automatic methods for **orientation, length and spacing/intensity**

Comprehensive outcrop description

- Increased statistical significance of parameters and distribution function
- Spatial trends
- Measurements in inaccessible/dangerous locations
- Large database
- Time-saving



Seismic data

10^1m

TLS (reservoir analogues)

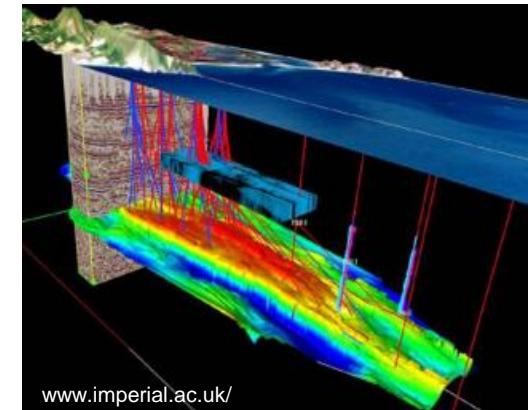
10^0m

Well logs

10^{-1}m

Laboratory

10^{-2}m



Motivation

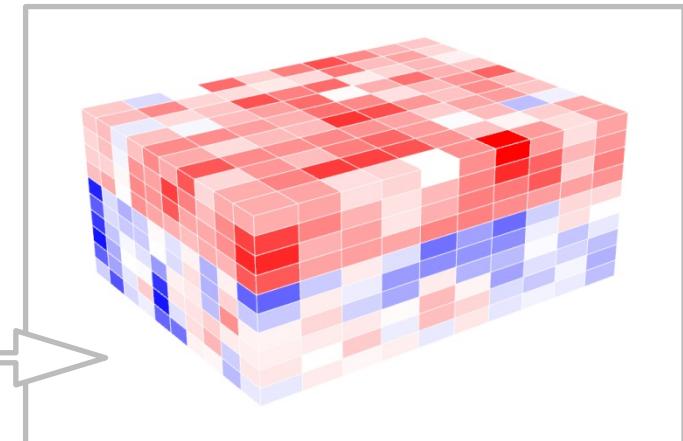
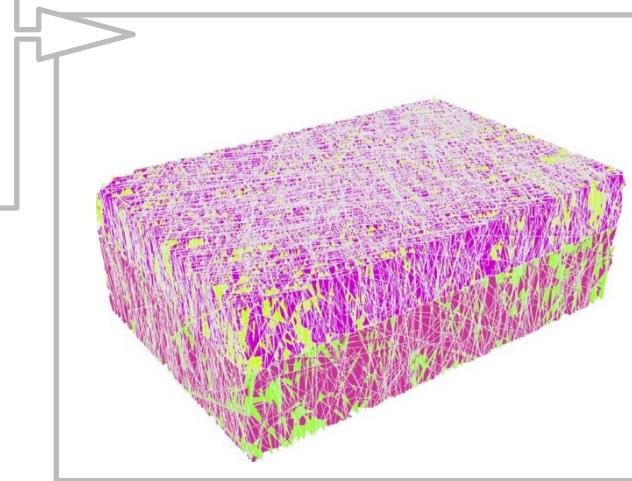
Challenges

Methods

Conclusion

Manual data input - Validation

- Termination criteria
- Aperture
- Type



final validation of DFN
model requires
calibration against
actual production data

Motivation



Challenges



Methods



Conclusion

Bottom Line

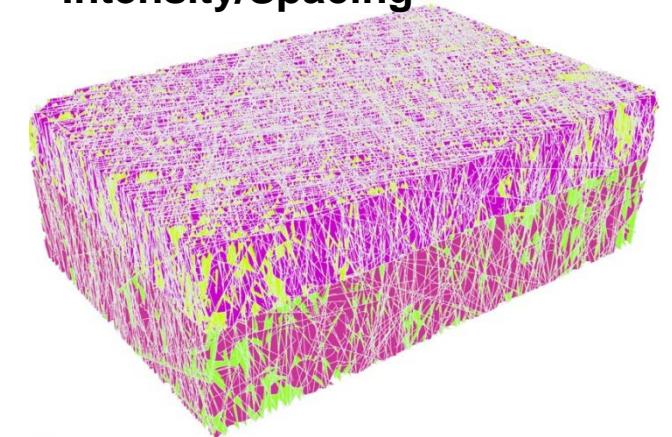
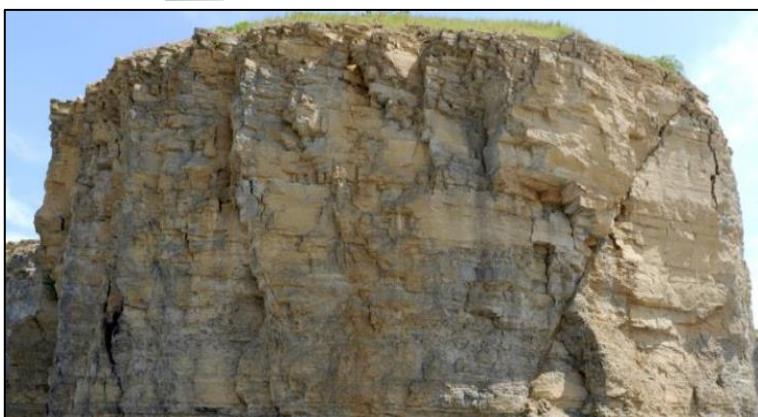
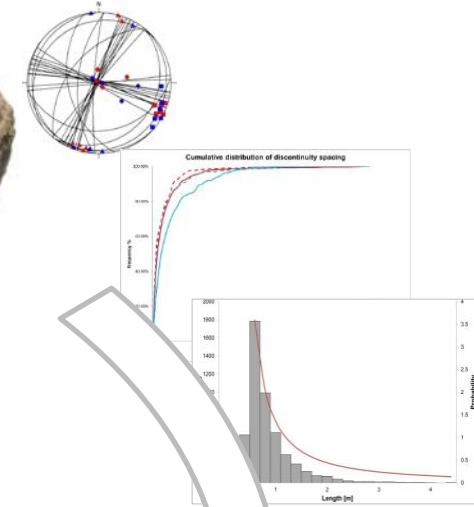
(Semi-) Automatic fracture quantification



Digitisation



Orientation
Length
Intensity/Spacing



Thanks for your attention!



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Acknowledgements

