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# fractopo: A Python package for fracture network analysis

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**Software**

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## Summary

In the Earth's crust, networks of approximately planar discontinuities, fractures, form intricate networks where they cross-cut and abut each other. These fractures control the stability of the crust and act as pathways for fluid flow and subsequently, transfer of geothermal heat and contaminants. Fractures can be observed from exposed bedrock surfaces where these discontinuities appear as two-dimensional fracture traces. Digitizing these fracture trace observations (e.g., from drone imaged outcrops) results in georeferenced two-dimensional trace vector datasets (i.e., fracture networks), which offer a cross-sectional window into the three-dimensional networks within the bedrock.

To analyze these datasets, Geographic Information System (GIS) tools are typically used to perform geospatial operations and analysis of the data. However, these tools are not specialized to handle the specific requirements for geometric and topological consistency of the fracture trace data and lack programmability to define repeatable workflows. To fill these gaps, `fractopo` provides geometric and topological validation, specifically tailored for fracture trace data, and a set of highly specific geospatial analysis tools, including plotting of the results. In contrast to GIS tools, `fractopo` is more readily usable in Python scripts and data pipelines which allow for better reproducibility of results.

## Statement of need

The Python package, `fractopo`, provides the tooling for i) data validation and ii) analysis of fracture network data (Figure 1). The fracture trace data is most commonly produced from base maps (e.g. drone images of outcrops or digital elevation models) by manual digitization. Consequently, a number of digitization errors can occur in the trace data related to the geometric consistency of the traces (e.g. traces must be continuous i.e. without breaks between segments) or topological consistency (e.g. a trace can be interpreted to abut another trace only if it is within a certain threshold distance from the other trace or if the endpoint of one is a point along the other). To tackle the validation problem, `fractopo` uses the `geopandas` (Jordahl et al., 2022) and `shapely` (Gillies et al., 2022) Python packages to conduct a high variety of geometric consistency checks to find topologically invalid traces that are the result of common digitization errors which are then reported to the user as attributes of the trace data.

To analyse the trace data, the user can simply input the validated traces along with its associated digitization boundary (i.e., target area). Based on these data, a number of analysis results in the form of `matplotlib`/`seaborn` (Hunter, 2007; Waskom, 2021) plots and as numerical data in the form of `numpy` arrays and `pandas` dataframes can be generated. The results (Figure 2) include rose plots of the orientation of the traces (Sanderson & Peacock, 2020), power-law length distribution analysis of the lengths of traces (Alstott et al., 2014; Bonnet et al., 2001), cross-cutting and abutting relationships between predefined azimuth sets, fracture intensities (Sanderson & Nixon, 2015) and topological ternary plots (Manzocchi,

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2002; Sanderson & Nixon, 2015). The package bears much similarity, and is inspired by, `NetworkGT` (Nyberg et al., 2018) which first provided a workflow for analysis of fracture trace data, including the determination of topological branches and nodes. However, the tight integration of `NetworkGT` with `QGIS` causes the package to be less friendly to development as it restricts the use of `NetworkGT` strictly inside `QGIS` (or alternatively `ArcGIS`, but with an older version of `NetworkGT`). In contrast, `fractopo`, can be used anywhere with either the `conda`, `pip` or `nix` package managers and contains features absent from `NetworkGT`, such as the determination of cross-cutting relationships between groups of fractures.

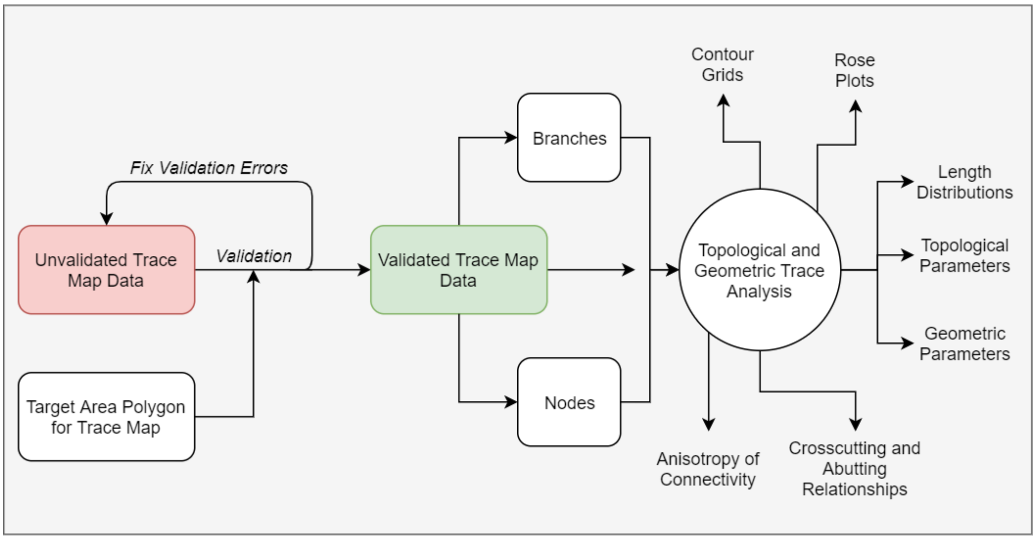


**Figure 1:** General workflow illustration of the data that `fractopo` takes and the available results.

Use of `fractopo` in research include two publications (Ovaskainen et al., 2022; Skyttä et al., 2021), three Master's Theses (Jokiniemi, 2021; Lauraeus, 2021; Ovaskainen, 2020) and assignments on a course, *Brittle Structures in Bedrock; Engineering Geology* at the University of Turku. Development of `fractopo` continues actively and the use of it continues in multiple ongoing academic works.

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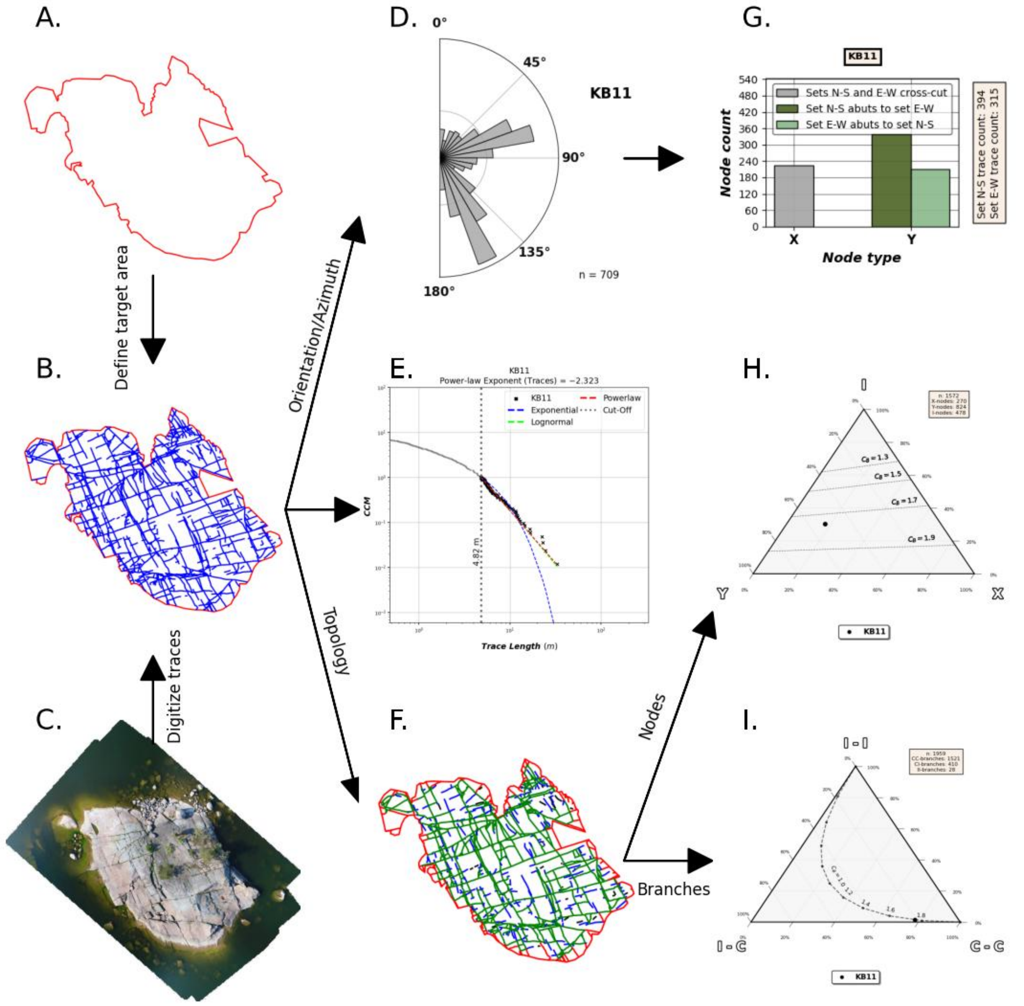


**Figure 2:** Visualisation of the workflow for fracture trace data analysis. A. Target area for trace digitisation. B. Digitized traces and target area. C. Orthomosaic used as the base raster from which the traces are digitized from. D. Equal-area length-weighted rose plot of the fracture trace azimuths. E. Length distribution analysis of the trace lengths. F. Determined branches and nodes through topological analysis. G. Cross-cut and abutting relationships between chosen azimuth sets. H. Ternary plot of node (X, Y and I) proportions. I. Ternary plot of branch (C-C, C-I, I-I) proportions.

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## References

Alstott, J., Bullmore, E., & Plenz, D. (2014). Powerlaw: A Python package for analysis of heavy-tailed distributions. *PLoS ONE*, *9*(1), e85777. https://doi.org/10.1371/journal.pone.0085777

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), 347–383.

https://doi.org/10.1029/1999RG000074

Gillies, S., Wel, C. van der, Van den Bossche, J., Taves, M. W., Arnott, J., Ward, B. C., & others. (2022). *Shapely*. https://github.com/shapely/shapely

Hunter, J. D. (2007). Matplotlib: A 2D graphics environment. *Computing in Science & Engineering*, *9*(3), 90–95. https://doi.org/10.1109/MCSE.2007.55

Jokiniemi, J. (2021). *3D-modelling of fault-induced small-scale secondary fracturing in crystalline rocks* [PhD thesis, University of Turku]. https://urn.fi/URN:NBN:fi-fe2021080642375

Jordahl, K., Bossche, J. V. den, Fleischmann, M., McBride, J., Wasserman, J., Richards, M., Badaracco, A. G., Snow, A. D., Gerard, J., Tratner, J., Perry, M., Ward, B., Farmer, C., Hjelle, G. A., Cochran, M., Taves, M., Gillies, S., Caria, G., Culbertson, L., … Mesejo-León, D. (2022). *Geopandas/geopandas: V0.12.1*. Zenodo. https://doi.org/10.5281/zenodo.7262879

Lauraeus, M. (2021). *3D-modelling of microfracture networks associated with faulting in the crystalline Wiborg rapakivi granite* [PhD thesis, University of Turku]. https://urn.fi/URN:NBN:fi-fe2021112957679

Manzocchi, T. (2002). The connectivity of two-dimensional networks of spatially correlated fractures: CONNECTIVITY OF TWO-DIMENSIONAL NETWORKS. *Water Resources Research*, *38*(9), 1-1-1-20. https://doi.org/10.1029/2000WR000180

Nyberg, B., Nixon, C. W., & Sanderson, D. J. (2018). NetworkGT: A GIS tool for geometric and topological analysis of two-dimensional fracture networks. *Geosphere*, *14*(4), 1618–1634. https://doi.org/10.1130/GES01595.1

Ovaskainen, N. (2020). *Scalability of lineament and fracture networks within the crystalline Wiborg Rapakivi Batholith, SE Finland* [PhD thesis, Turun Yliopisto]. http://urn.fi/URN:NBN:fi-fe202003259211

Ovaskainen, N., Nordbäck, N., Skyttä, P., & Engström, J. (2022). A new subsampling methodology to optimize the characterization of two-dimensional bedrock fracture networks. *Journal of Structural Geology*, *155*, 104528. https://doi.org/10.1016/j.jsg.2022.104528

Sanderson, D. J., & Nixon, C. W. (2015). The use of topology in fracture network characterization. *Journal of Structural Geology*, *72*, 55–66. https://doi.org/10.1016/j.jsg.2015.01.005

Sanderson, D. J., & Peacock, D. C. P. (2020). Making rose diagrams fit-for-purpose. *Earth-Science Reviews*, *201*, 103055. https://doi.org/10.1016/j.earscirev.2019.103055

Skyttä, P., Ovaskainen, N., Nordbäck, N., Engström, J., & Mattila, J. (2021). Fault-induced mechanical anisotropy and its effects on fracture patterns in crystalline rocks. *Journal of Structural Geology*, *146*, 104304. https://doi.org/10.1016/j.jsg.2021.104304

Waskom, M. (2021). Seaborn: Statistical data visualization. *Journal of Open Source Software*, *6*(60), 3021. https://doi.org/10.21105/joss.03021