Evaluation of fracture network connectivity based on topology for geothermal resources assessment in Kuujjuaq, Northern Québec, Canada

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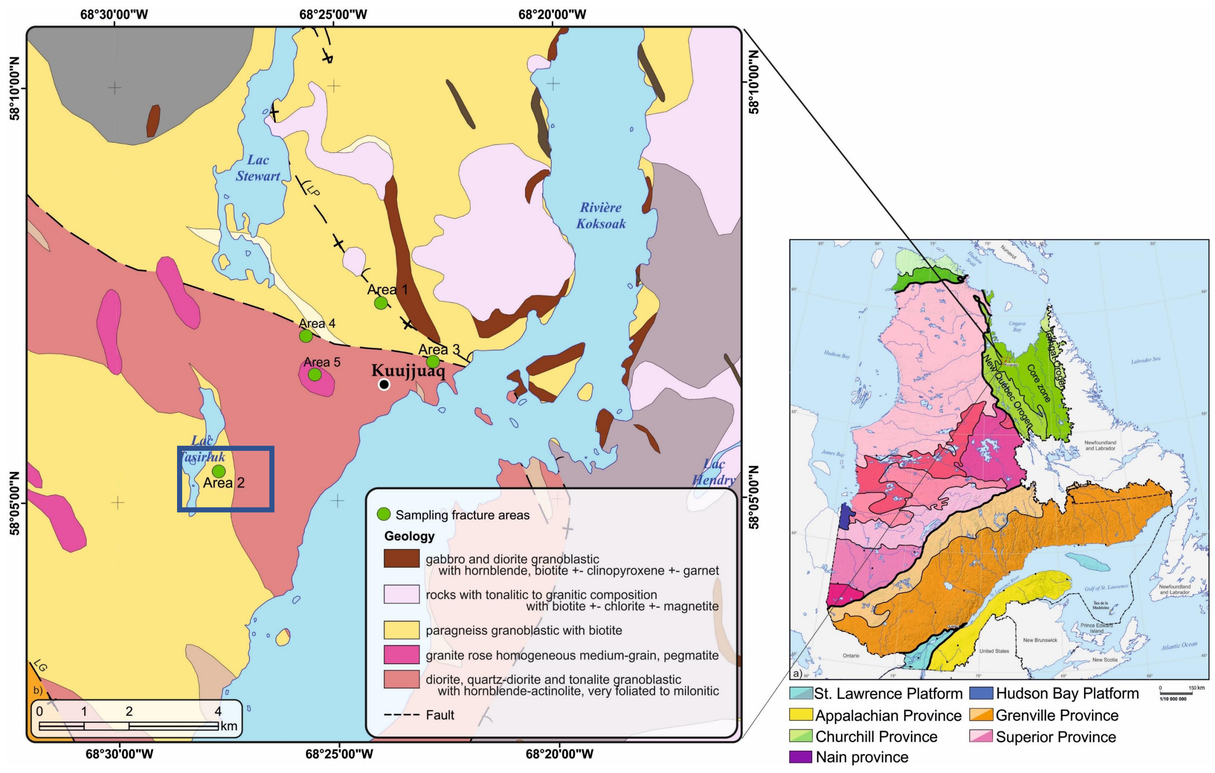
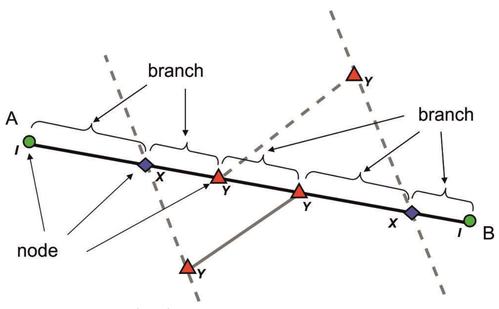
Scope and objective

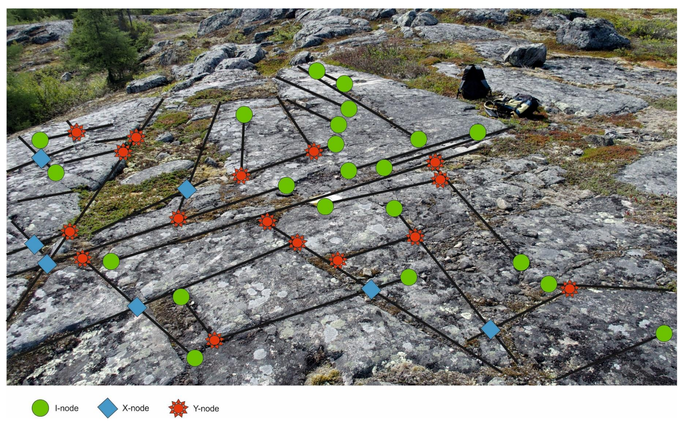
The present work is part of a project carried out in Nunavik, Northern Québec, whose main objective is to assess the potential of deep geothermal resources with the Inuit community of Kuujjuaq as case study. In a crystalline rock media, the presence of interconnected fracture network plays a major role for the exploitation of deep geothermal resources. The present work aims at characterizing the fracture network connectivity following a topological method.

Fracture networks are complex systems that can be approached using topology to describe their spatial relationships. In geological outcrops, the complex fracture network can be transformed to an equivalent 2D system consisting of lines, branches and nodes.





Sanderson and Nixon (2015)

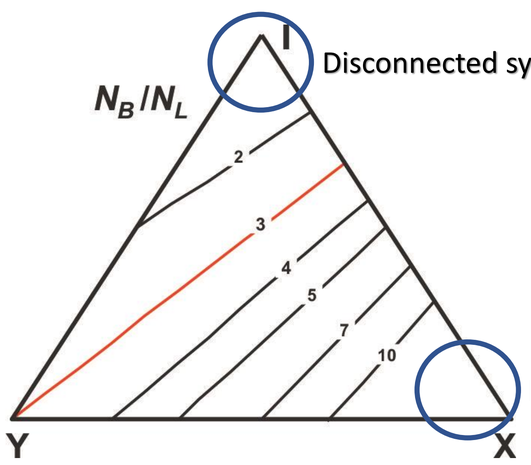


This method enables to qualitatively and quantitatively characterize the fractures and the network properties by recording the different groups of fracture terminations and analyze the data by simple relationships and ternary diagrams.

Fracture terminations can be recorded as:

- cross-cutting fractures – X-nodes
- abutments – Y-nodes
- isolated tips – I-nodes

Ratio number of branches per lines → connectivity

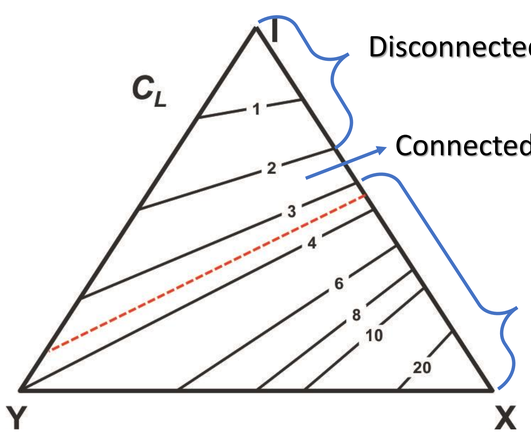


Disconnected system

$$\frac{N_B}{N_L} = \frac{N_I + 3N_Y + 4N_X}{N_I + N_Y} \qquad \frac{N_B}{N_L} = 3.33$$

Highly connected system

Connections per line → critical connectivity



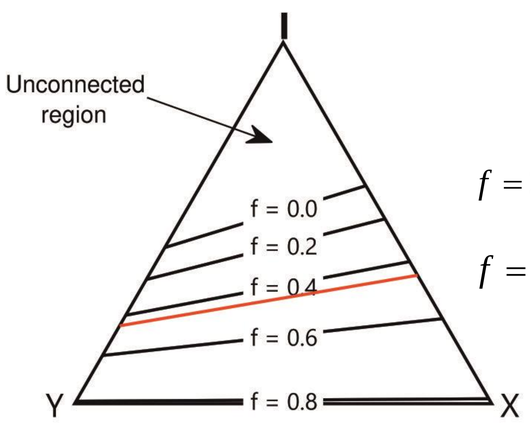
Disconnected system; no percolation threshold

Connected system; orientation-clustered system

Connected system; density-clustered system

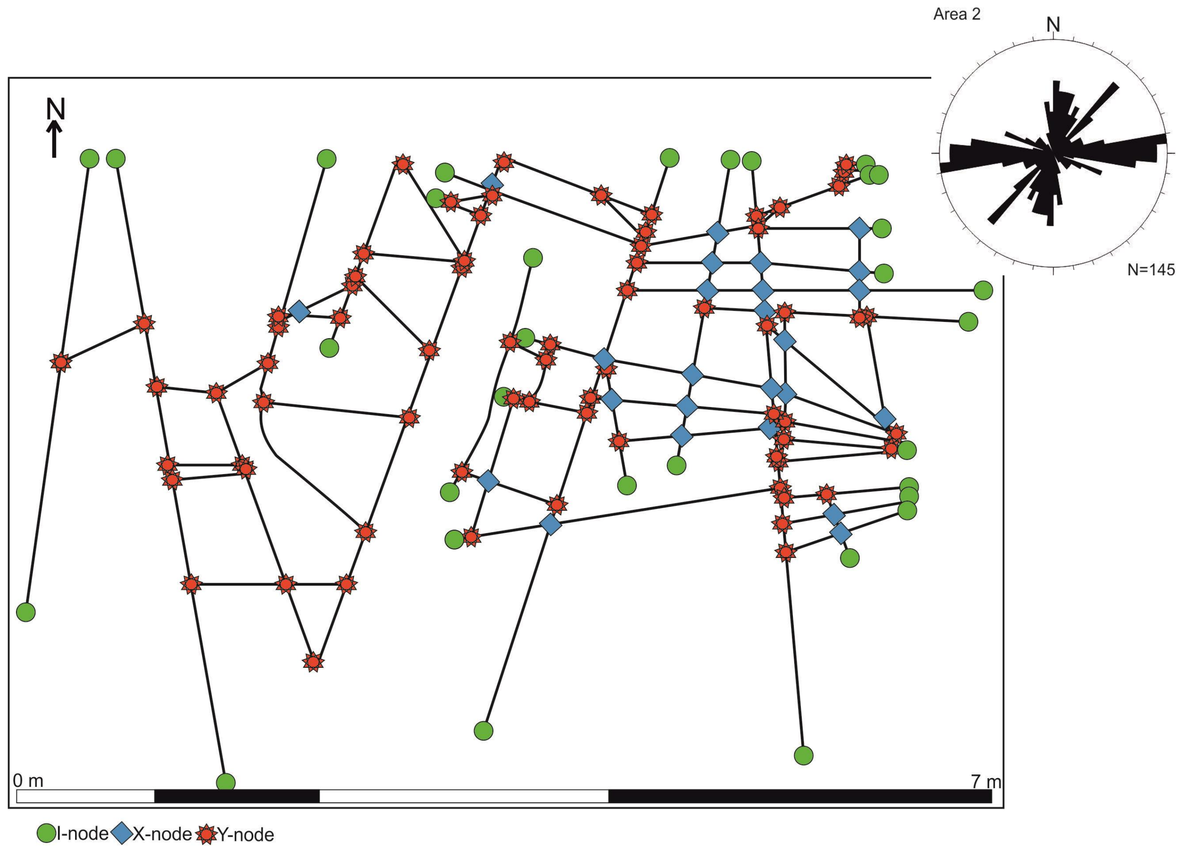
$$C_L = 4\frac{N_Y + N_X}{N_I + N_Y} \qquad C_L = 3.69$$

Hydraulic connectivity



$$f = 2.94 \times C_f - 2.13$$

$$f = 0.46$$



Area 2 – fracture network characterization

- Lithology: paragneiss;
- Orientation: E-W with scattered joints along NNE-SSW;
- Length: 0.2 – 10 m;
- Aperture: 0 – 48.85 mm;
- Spacing: 1.1 ± 1.2 m → CV = 1.1 m → density-clustered fractures;
- Density: 1.2 m^{-1};
- Number of nodes: 128 → 33 I-nodes + 25 X-nodes + 70 Y-nodes;
- Partially connected system;
- Critical connectivity within the range of density-clustered systems;
- Potential hydraulic connectivity: 50 %.

This natural fracture system has clustered fractures; however, a clustered network does not necessary mean that fractures are permeable and interconnected. Based on topology and percolation theories, it was observed that this system is only partially connected, with a potential hydraulic connectivity of approximately 50 %. This is due to the several joints that end as isolated tips (I-nodes).