A global assessment of effective fracture porosity in crystalline rocks

Josse van den Berg[1], Elco Luijendijk[1] & Grant Ferguson[2]

1: Department of Earth Science, University of Bergen, Bergen, Norway (josse.berg@uib.no)
2: School of Environment and Sustainability, University of Saskatchewan, Saskatchewan, Canada

1. Facture porosity important but poorly constrained

- Fracture porosity and fracture density control fluid flow in crystalline rocks and are critical for hydrogeology, contaminant transport, and nuclear waste safety.
- Effective fracture porosity in crystalline rocks is poorly constrained due to measurement challenges and regionally biased datasets.
- A porosity of ~1% is widely assumed, often without strong empirical support (Banks & Robins, 2002).
- Large global permeability datasets offer a way to estimate fracture porosity and density indirectly.
- **How does effective fracture porosity in crystalline rocks vary with depth at global scale?**

2. Estimating porosity

- Global permeability compilation (n = 27,966) from crystalline rocks (Achtziger-Zupančič et al., 2017; Kuang & Jiao, 2014).
- Effective fracture porosity derived indirectly from permeability, using an analytical relationship based on Snow (1968) and extended to include fracture roughness and depth dependent aperture.
- Porosity–depth relationships quantified using log–log regression and non parametric statistics.
- Uncertainty assessed using Monte Carlo simulations and bootstrap resampling to compare parameter uncertainty with natural variability.
- Geological controls evaluated by testing rock type, tectonic setting, and plate boundary class after correcting for depth.

Fig 1: Methods flowchart

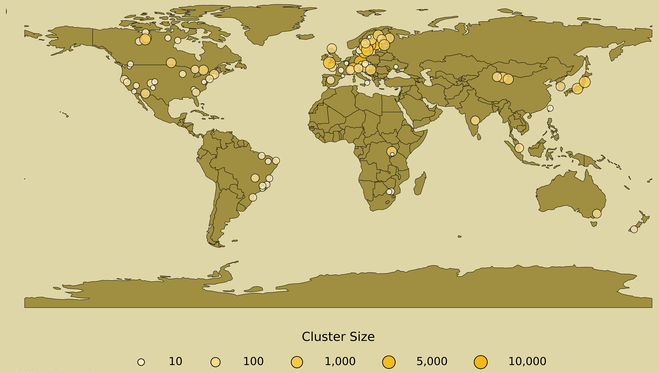

Fig 2: Distribution of permeability datapoints

3. Global porosity-depth trends.

Porosity decreases exponentially with depth across the entire crustal range, with a statistically significant negative relationship between depth and porosity.

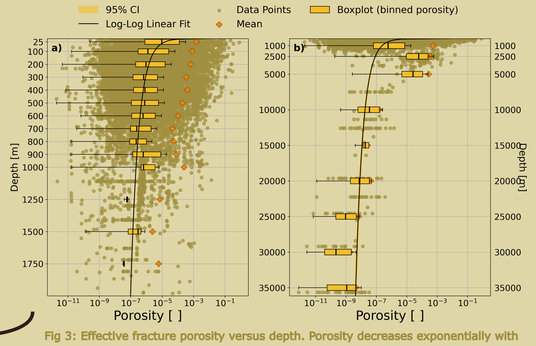

Fig 3: Effective fracture porosity versus depth. Porosity decreases exponentially with depth and shows strongly right-skewed distributions

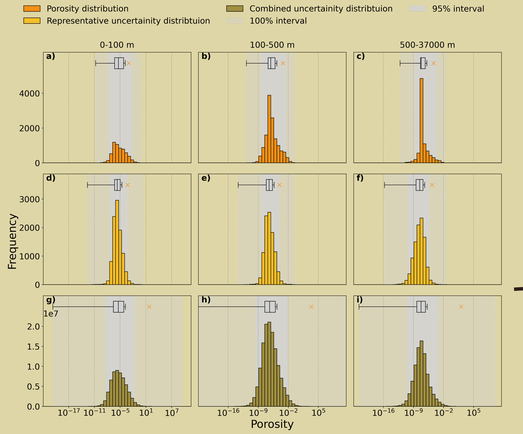

Fig 4: Porosity distributions and uncertainty across depth intervals. Distributions are highly right-skewed; uncertainty has little effect on median values.

4. Uncertainity and variation of porosity

- Porosity distributions are highly right skewed at all depths, with median porosity orders of magnitude lower then the commonly assumed 1% --> **median more representative then mean.**
- Porosity distributions become more compact with depth, indicating reduced variability in deeper crustal levels.
- Uncertainty of individual porosity estimates is small compared to natural variability. This shows that observed scatter is dominated by geological heterogeneity rather than parameter uncertainty.
- Aggregated uncertainty has little effect on median and IQR, but inflates the mean due to extreme outliers --> use robust statistics

5. Porosity and geological setting

- **Depth is the dominant control on porosity, but rock type** (fig. 5) **and geological setting introduce small yet statistically significant deviations from the global depth trend.**
- Shields, cratons, and accretionary complexes show slightly higher porosity than expected for depth, while orogenic belts, volcanic arcs, and rifts tend to show lower porosity.

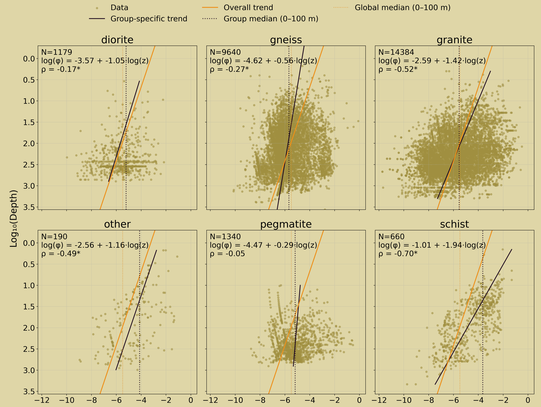

Fig 5: Porosity distributions and uncertainty across depth intervals. Distributions are highly right-skewed; uncertainty has little effect on median values.

6. Effective fracture porosity lower than commonly assumed

- Fracture porosity distributions in crystalline rocks are highly right skewed, making median values more representative than means.
- Porosity decreases exponentially with depth, which is the primary global control.
- Rock type and geological setting add secondary but significant variability.
- Lower fracture porosity implies important hydrogeological consequences, including reduced groundwater storage and faster groundwater and contaminant transport for a given flux.

7. References

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Abstract

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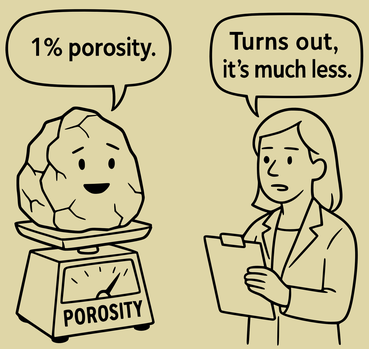

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