Characterizing deep fracture zones within the natural barrier
: Insights from borehole data around the KAERI underground research tunnel

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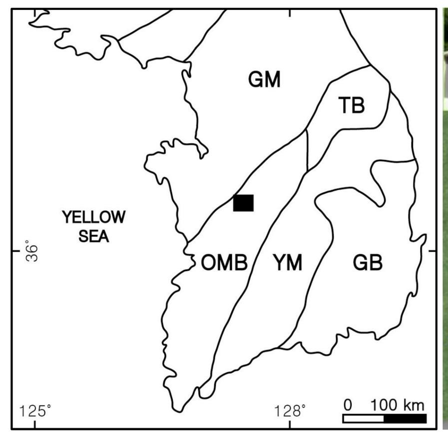
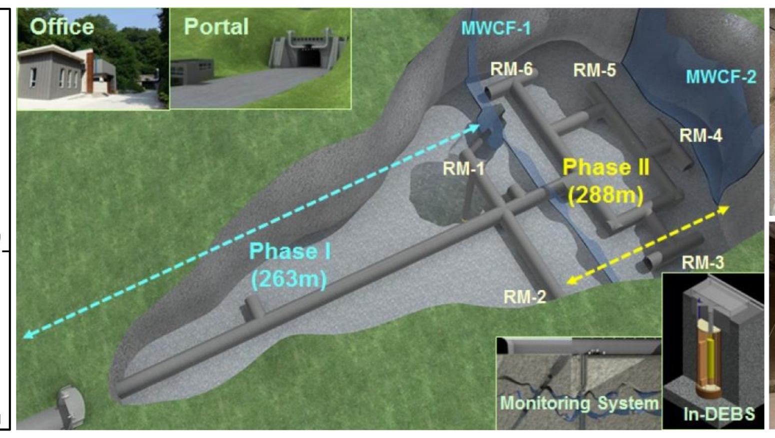
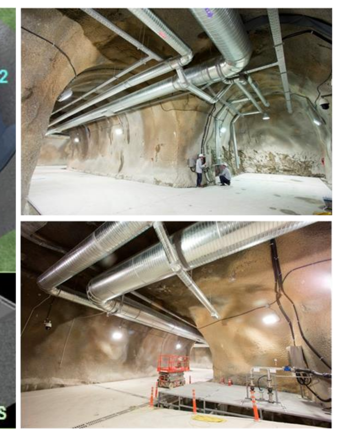
Introduction

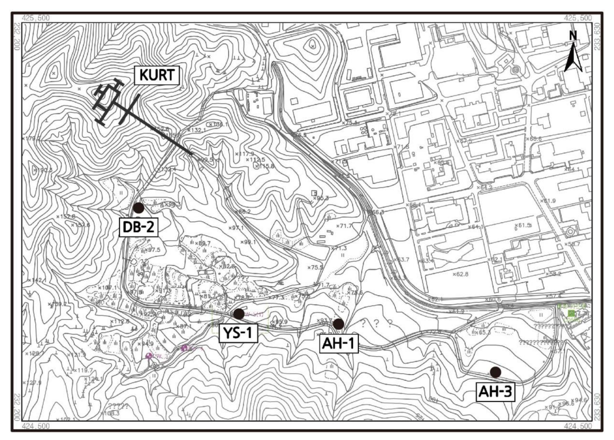


The geotectonic map of the Korean Peninsula (black box: study area)

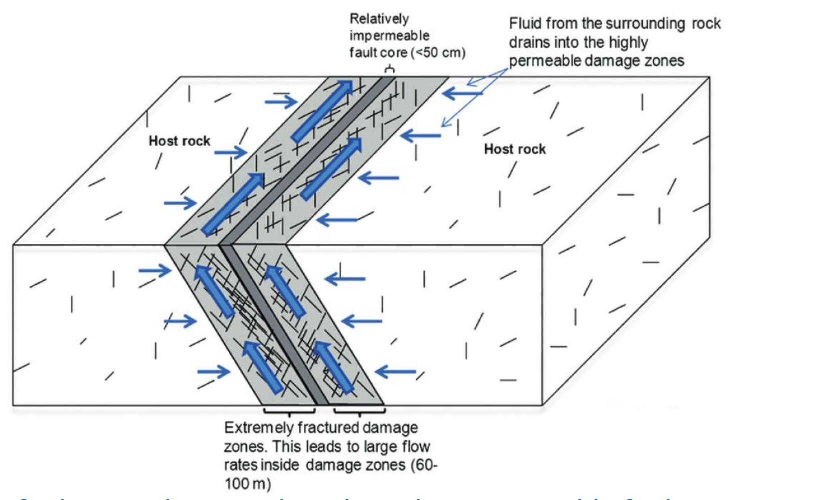


Schematic diagram of KURT


Inside the KURT



Location map of the boreholes around KURT area used in this study



A fault zone showing the relatively impermeable fault core surrounded by the highly fractured damage zone [Madhur et al., 2014]

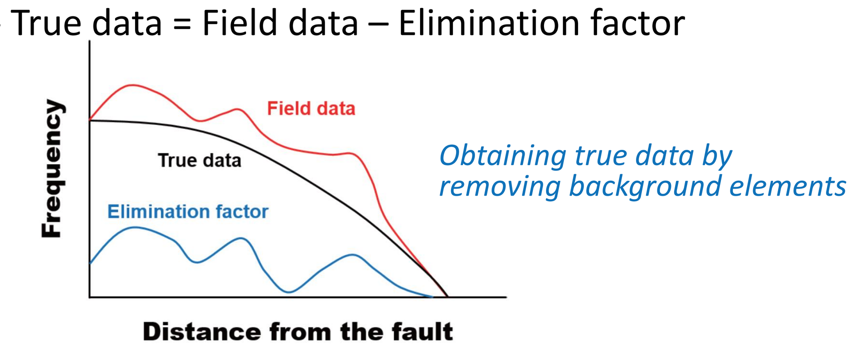
- **Structural elements in performance assessment of natural barrier**
  - Pathways for groundwater flow
  - Structural factors: joints, fractures, faults etc.
  - Fault zone consisting of 'impermeable fault core' & 'highly fractured damage zone'
- **Materials used in this research**
  - Drill cores excavated around KURT: about 500 m (AH-1, YS-1), 1,000 m (AH-3, DB-2)
  - BHTV (Borehole Televiewer) & BIPS (Borehole Image Processing System)

[General information about four boreholes used in this study]

Borehole ID	Drill Direction	Horizontal Coordinates		Ground Level (EL. m)	Drill Depth (m)
		Northing	Easting		
AH-1	vertical	324,745	232,989	89.80	450
AH-3	vertical	324,619	233,388	82.60	1,000
DB-2	vertical	325,032	232,498	108.16	1,000
YS-1	vertical	324,767	232,743	83.55	500

Methodology (boundary of deep fracture zones)

- **Background fracture (elimination factor)**
  - True data = Field data – Elimination factor

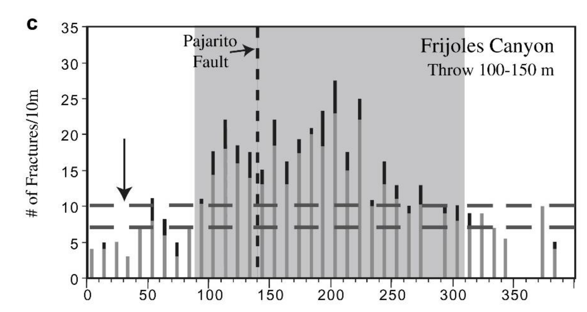


Obtaining true data by removing background elements

- **Spacing analysis to determine background fracture**
  - Spacing: distance between fracture & next fracture
  - Slope change in cumulative percentage of spacing
- **Classification according to the degree of clustering of deformation bands**
  - 1st: many single multi-strand bands, with anastomosing slip-surfaces
  - 2nd: several single multi-strand bands, with discrete slip-surfaces
  - 3rd: few single multi-strand bands, with no slip-surfaces

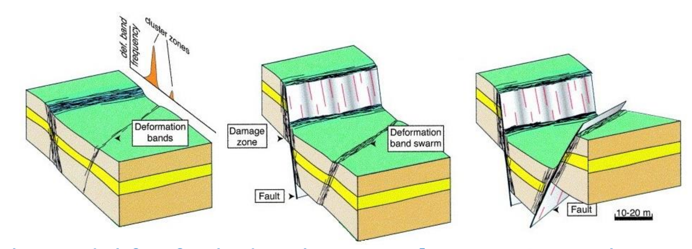

Examples of the cluster classes in damage zone [Shipton & Cowie, 2001]

- **Frequency of fracture = Background frequency**
  - Fault damage zone: where fracture density is consistently ≥ 10/10m

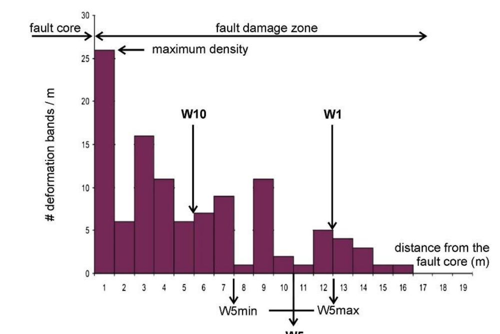


Number of fractures per 10 m interval from transects in example fault. Shaded region is damage zone (≥10/10 m) [Riley et al., 2010]

- **Edges of clustering deformation bands**
  - Deformation band: narrow deformation zone, prior to fault formation
  - Clustering zone: concentration of deformation bands
  - Fault damage zone: point at which the deformation bands are clustered

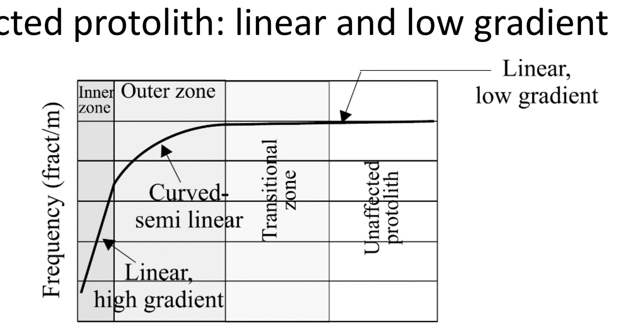

A simple model for fault development [Fossen & Hesthammer, 2000]

- **First occurrence of a unit interval of no fractures**
  - Inner boundary: between chaotic fault core & fresh host rock
  - Outer boundary: the first occurrence of 3 m interval without fracture



Frequency graph illustrating different ways of defining the damage zone width [Schueller et al., 2013]

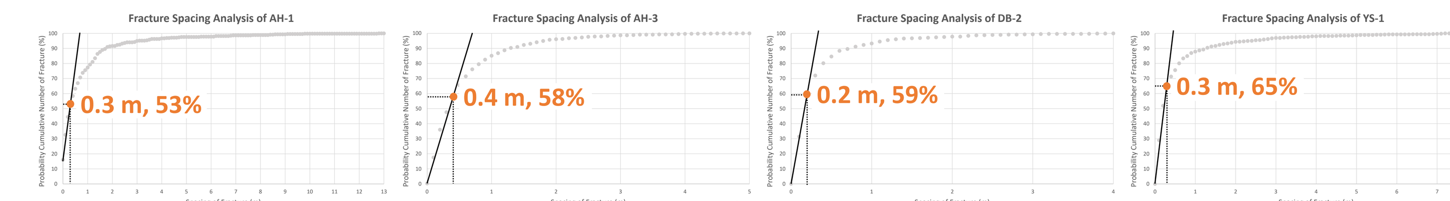
- **Slope changes of cumulative fracture frequency**
  - Inner damage zone: linear and high gradient
  - Outer damage zone: curved-semi linear
  - Unaffected protolith: linear and low gradient



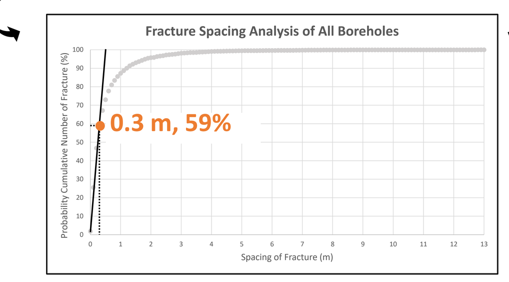
Deformation band frequency and cumulative frequency vs. distance from the fault core [Berg & Skar, 2005]

Results (in the KURT area)

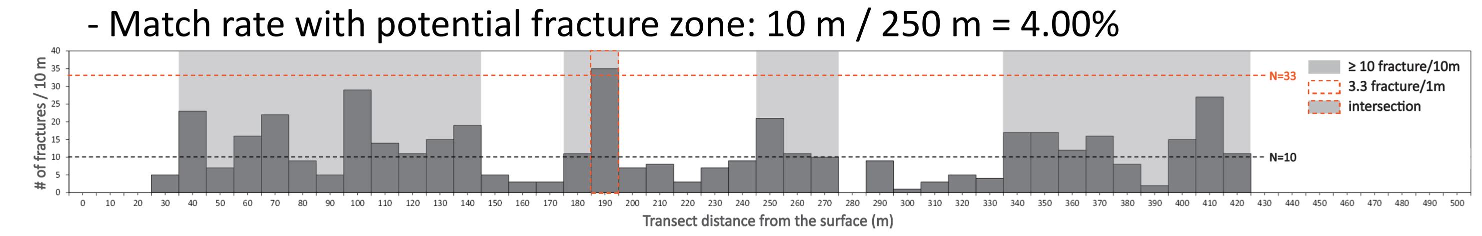
- **Potential fracture zone (AH-1, AH-3, DB-2, & YS-1)**
  - Results of spacing analysis (each borehole)
    - : AH-1: 53% of spacing is less than 0.3 m ⇒ spacing > 0.3 m or 3.3 fracture / m
    - : AH-3: 58% of spacing is less than 0.4 m ⇒ spacing > 0.4 m or 2.5 fracture / m
    - : DB-2: 59% of spacing is less than 0.2 m ⇒ spacing > 0.2 m or 5.0 fracture / m
    - : YS-1 : 65% of spacing is less than 0.3 m ⇒ spacing > 0.3 m or 3.3 fracture / m



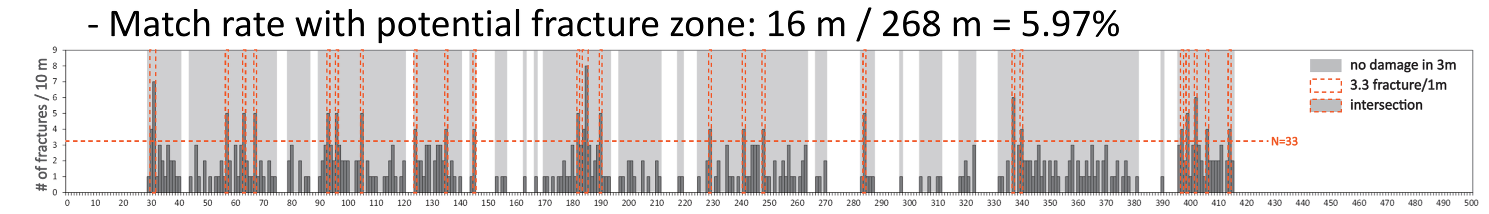
  - Representative values of spacing analysis (avg. of four boreholes in the KURT area)
    - : 59% of spacing in boreholes is less than 0.3 m ⇒ spacing > 0.3 m / 3.3 fracture/m



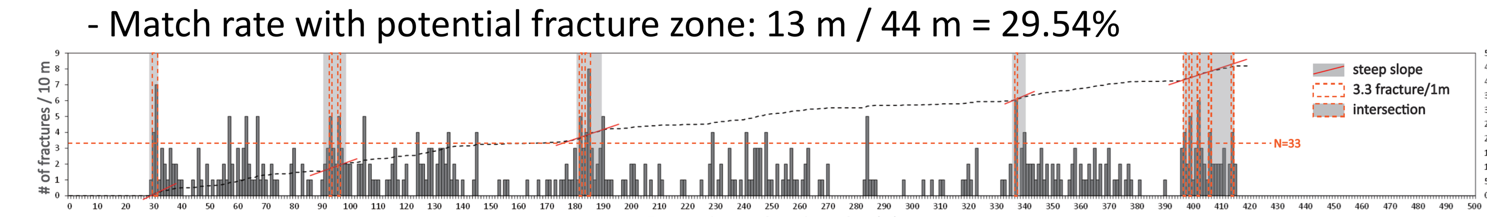
- **Frequency fractures equal to the frequency background level (AH-1)**
  - Setting: less than 10 fractures in 10 m interval
  - Match rate with potential fracture zone: 10 m / 250 m = 4.00%



- **The outer boundary from where there are no fractures for a certain distance (AH-1)**
  - Setting: without fracture for 3 m
  - Match rate with potential fracture zone: 16 m / 268 m = 5.97%

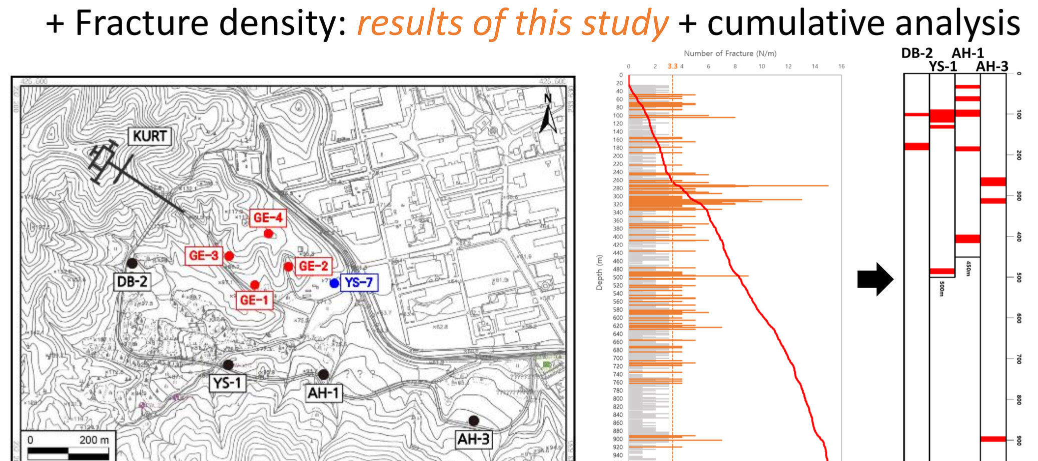


- **Density of fracture ∝ Gradient of the cumulative fracture frequency**
  - Setting: the section where the slope of the graph increases rapidly
  - Match rate with potential fracture zone: 13 m / 44 m = 29.54%

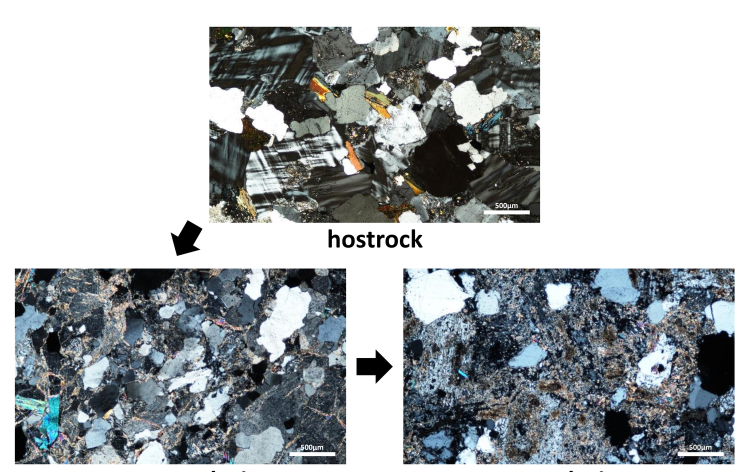


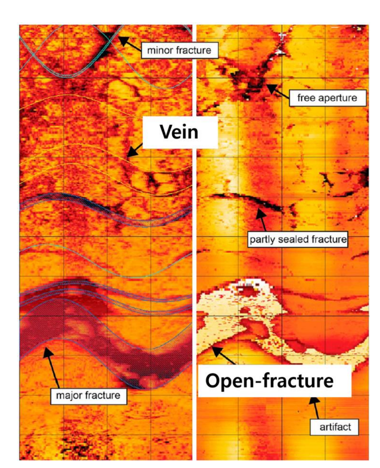
Complementary & Ongoing Studies

① Integration of fracture information from various depths
┌ Shallow data: surface geological survey (2D or 3D)
│ Intermediate data: GE-1, GE-2, GE3, GE-4 boreholes (1D)
└ Deep data: *results of this study* + YS-7 borehole (1D)
+ Fracture density: *results of this study* + cumulative analysis

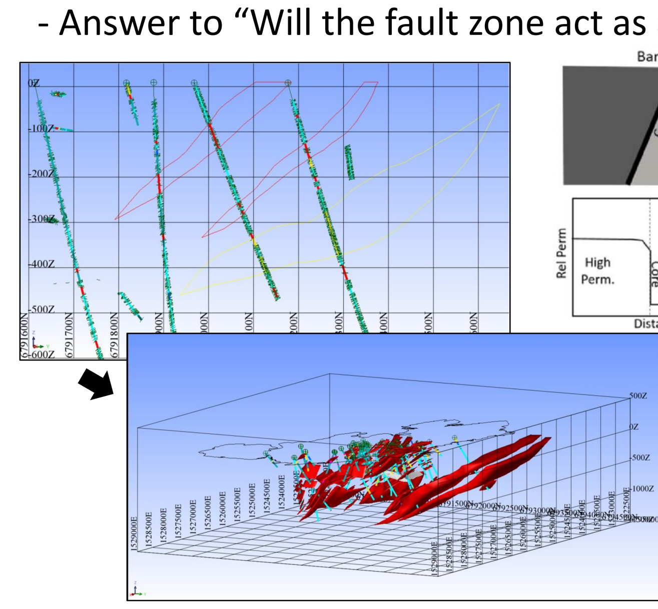


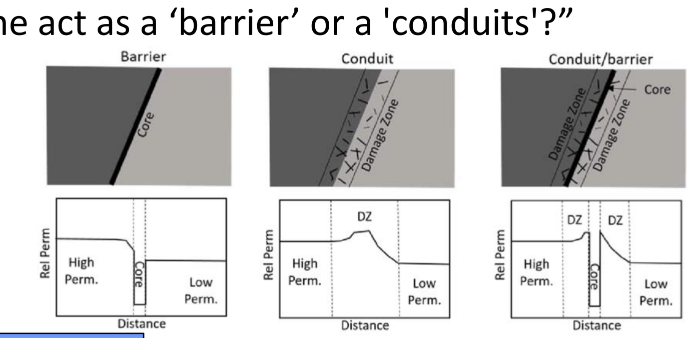
② Determining the distribution of deep fault rock
- Fault rocks: mylonite, cataclasite, fault breccia, fault gouge, etc.
- Methods: petrography (thin-section, slab), BHTV, BIPS
- Spatial pattern: depth, thickness *(results of this study)*, direction





①+② Assessment of fault zones within the natural barrier
- Answer to "Where are weak zones of the natural barrier?"
- Answer to "Will the fault zone act as a 'barrier' or a 'conduits'?"


◀ Lithological and structural data from the boreholes around the ONKALO tunnel [POSIVA-2016—16]



▲ Three conceptual models of how fault zones impact fluid flow properties [McCallum et al., 2016]

Key References

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