Contamination and Remediation in Fractured Rocks:

Future Research Priorities

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Toxics Project on Contamination in Fractured Rocks: Unique Attributes

- **Fractures + Matrix**
- **DNAPLs**
- **No Plume**
- **Aggressive Remediation**

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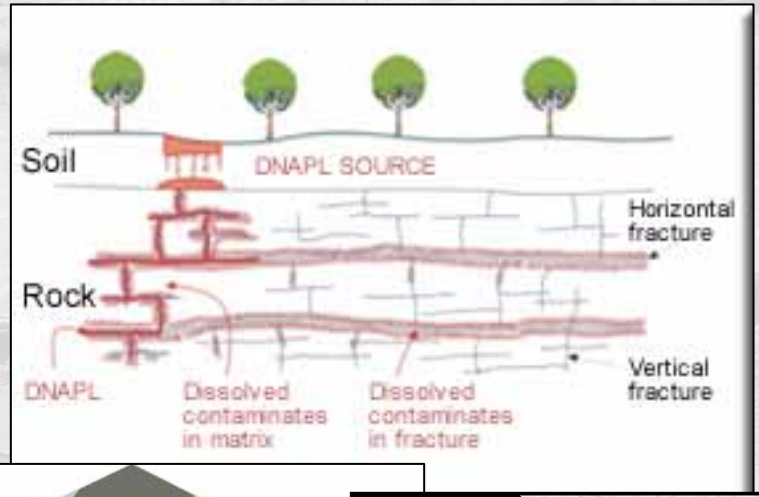
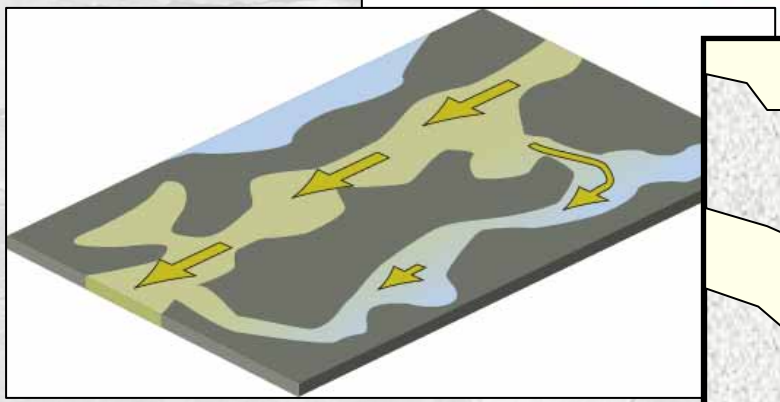
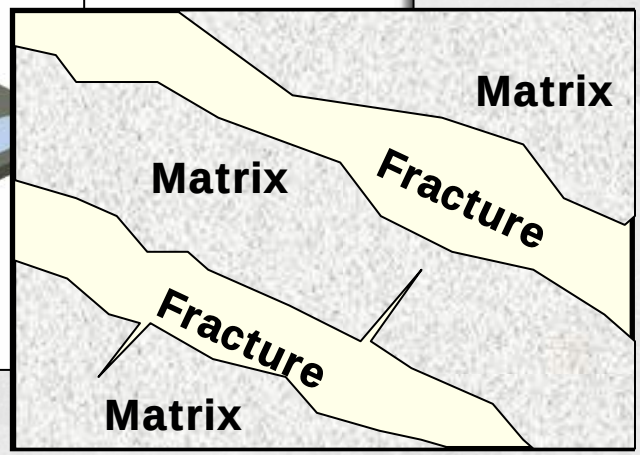
Processes Occurring at Multiple Scales



Fracture Networks



Fracture 'Plane' or Zone



Fracture-Matrix Interface

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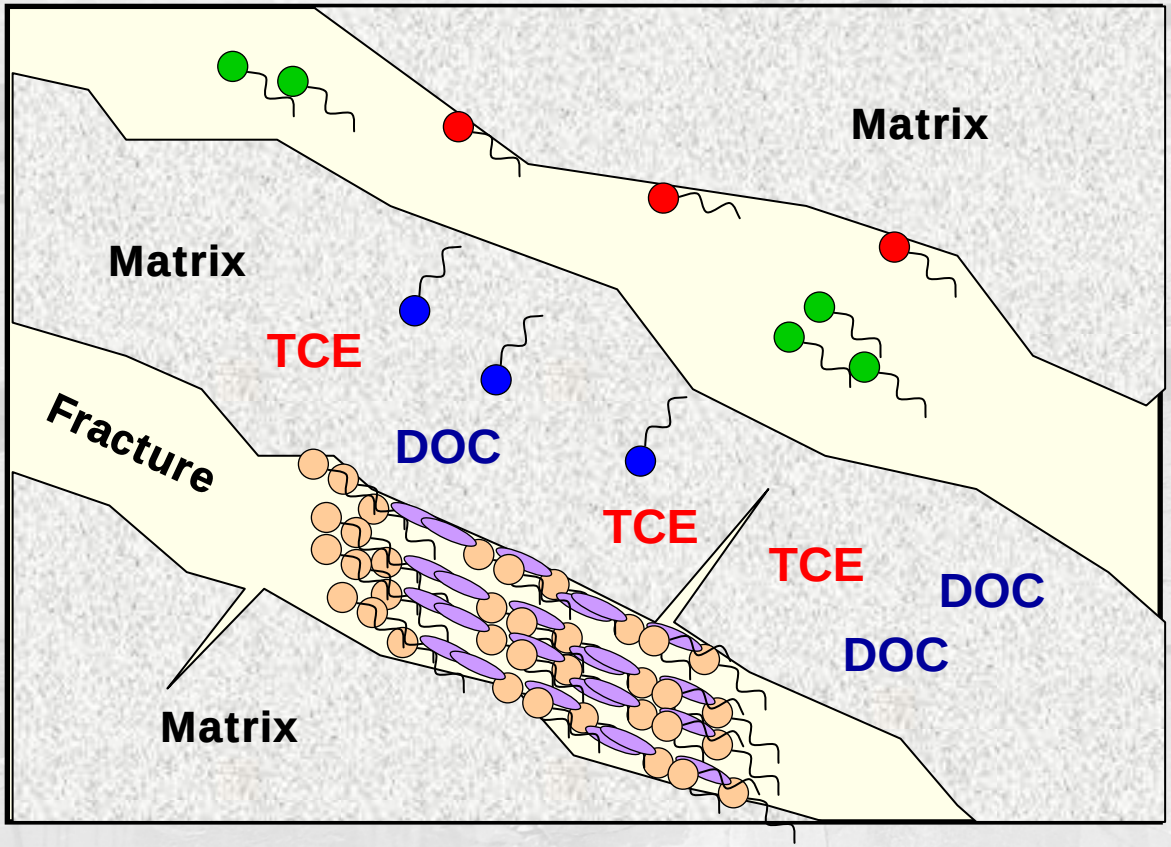
The Microbial Environment



Do biofilms develop?

Do biogeochemical reactions affect fracture permeability?

Roles of:
Attached microbes?
Mobile microbes?

Do contaminant-degrading microbes inhabit the matrix and dead end fractures?
e.g., by chemotaxis?

If so, are redox conditions & electron donor in the matrix conducive to reductive dechlor.?

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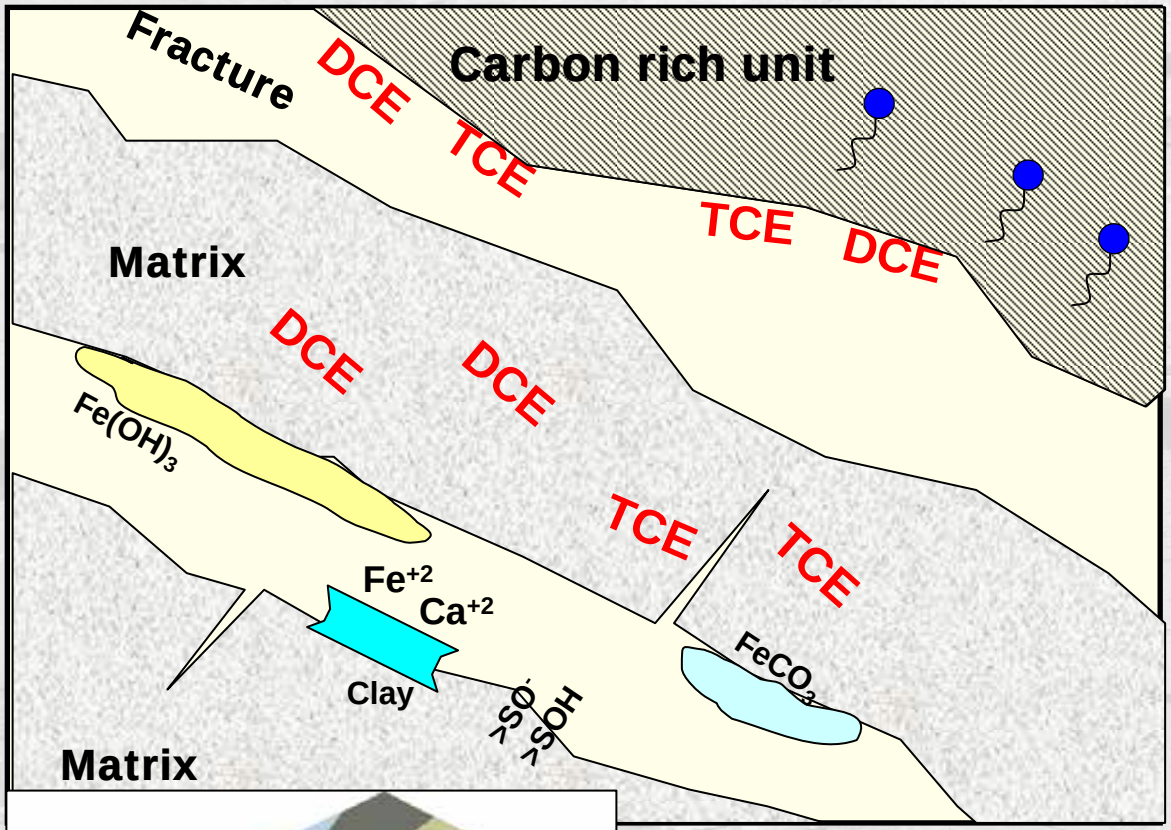
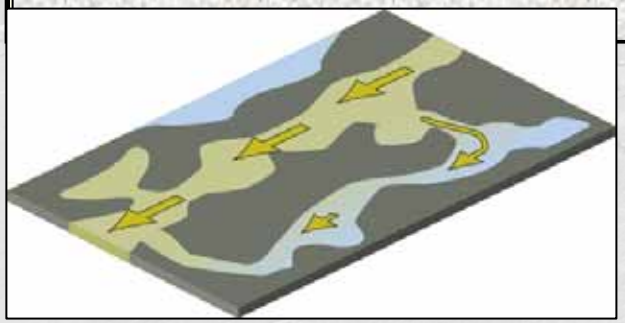
Fracture & Matrix Surface Processes





How does flow regime in fractures affect sorption and surface reactions?

Role of sorption on fracture surfaces and in rock matrix?

Effect of rock mineralogy on surface reactions?

In particular, role of organic carbon in rock on sorption and surface reactions?

Is this organic carbon bioavailable?

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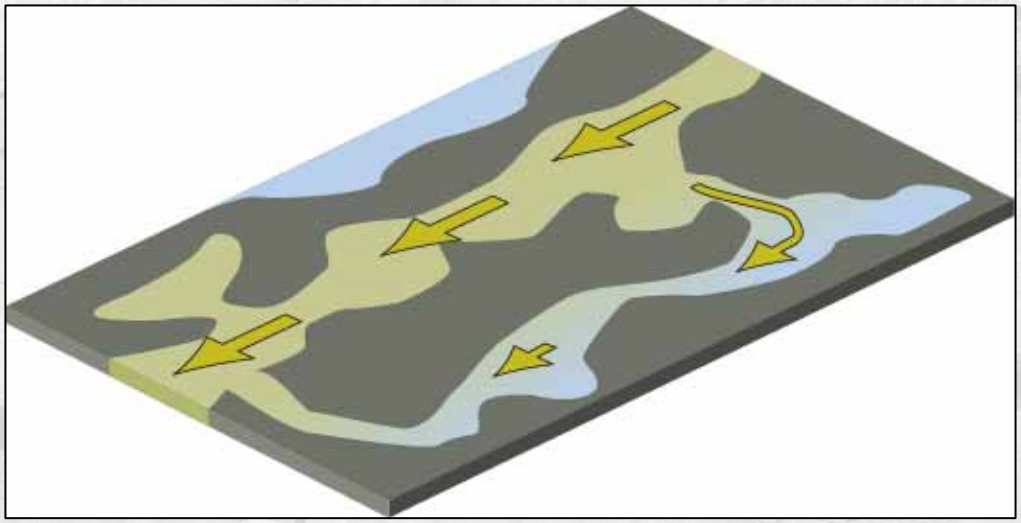
Contaminant Fate and Transport



A priori identification of dominant transport processes; e.g., Matrix diffusion versus slow advection.

Characterization of surface area within fracture planes/zones that is in contact with chemical transport.

Detection of hydraulically important high angle fractures.

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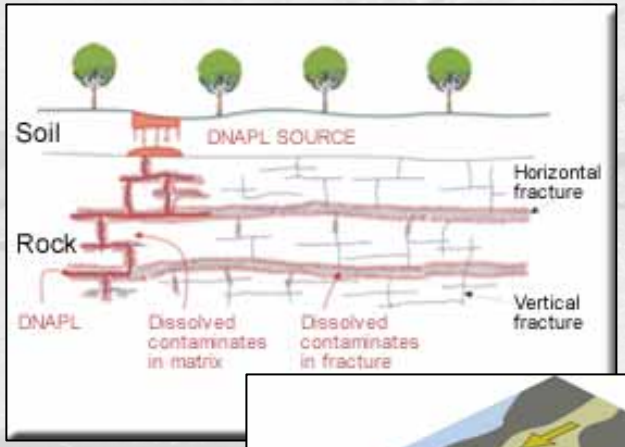
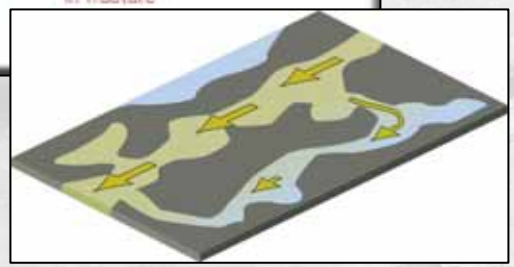
Where is the Contamination?





Many sources, original and secondary

Don't have a plume, have a heterogeneous distribution of contaminants

Research Priority: Need methods for estimating distribution of contaminants at site scale in fractured rock aquifers.

Aqueous phase & DNAPL

Critical to designing and monitoring remediation and containment

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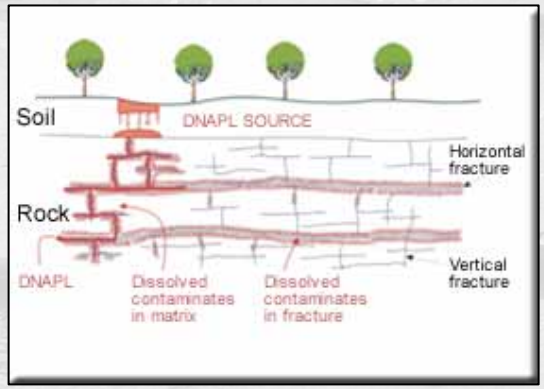
Estimating Contaminant Distribution and Fate & Transport Processes at Site Scale

Possible New Approaches:



- Combine **field measurements, process understanding, modeling**; include uncertainty quantification
- Borehole diffusion tests
- **Vapor monitoring** in shallow subsurface
- **Geophysical techniques**: New tools/methods for:
  - NAPL detection
  - Remote measurement of fluid flow
  - Fracture / low permeability zone characterization

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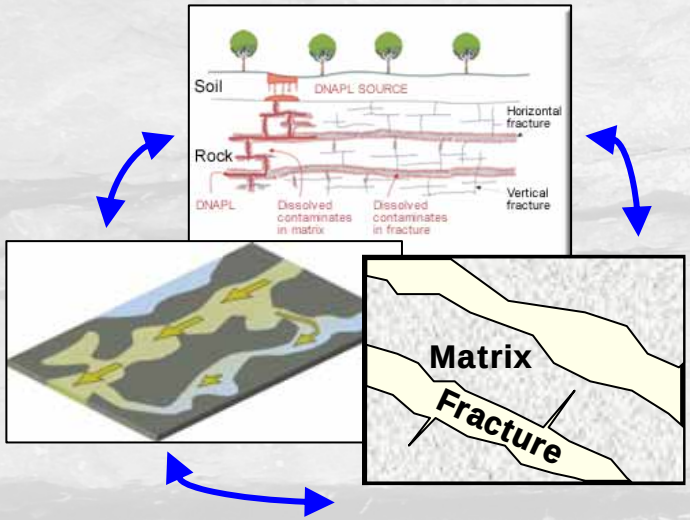
Remediation



All previously identified research priorities are important to designing, monitoring, and understanding processes of remediation.

Remediation activities themselves can be used as a basis for valuable research:

Use these activities as an opportunity for characterization and process understanding…

… and fold this understanding back into remediation design and monitoring strategies.

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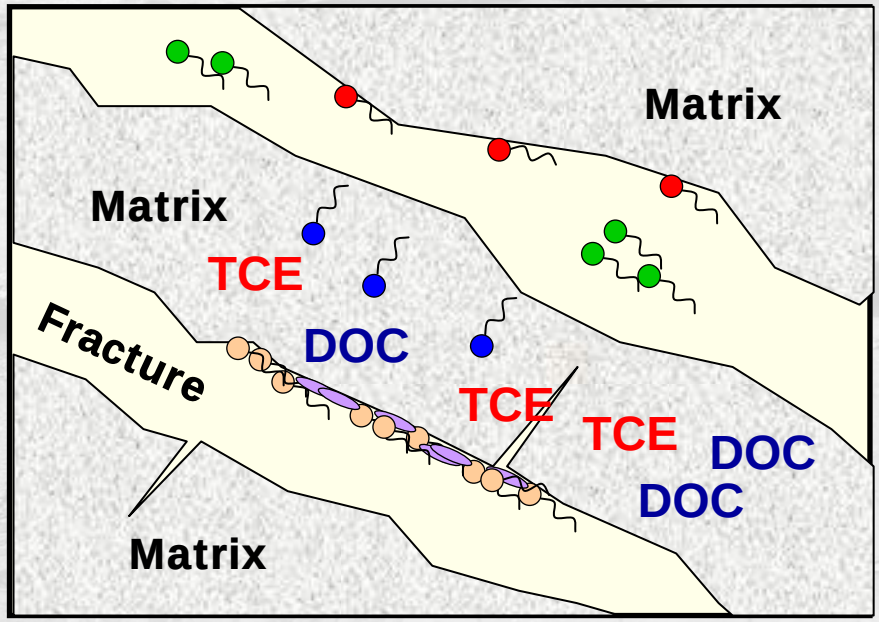
Remediation: Research Directions

Bioaugmentation:

- **Tremendous opportunity for research on microbially mediated contaminant degradation**
- **Combine field pilot test with lab and modeling studies for further process understanding**



- **Use to conduct research on geophysical monitoring methods; e.g. imaging, rate-limited mass transfer**
- **Use knowledge and insight gained to improve future bioaugmentation design and monitoring strategies**

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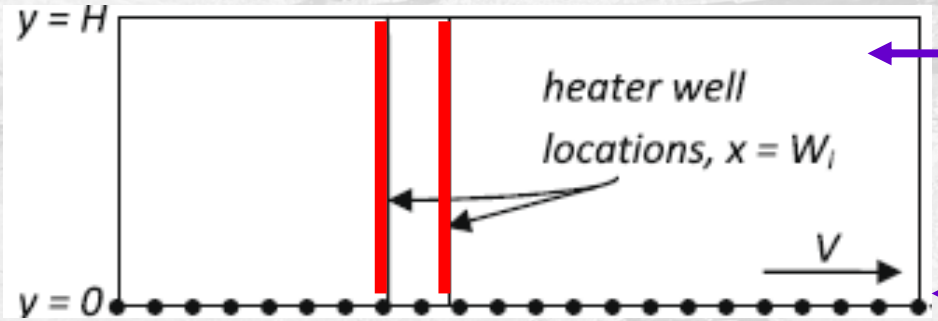
Remediation: Research Directions

Thermal Conductive Heating



Baston and Kueper, Adv. Water Res., 2008

- **Results from TCH pilot test can enable further understanding of: matrix diffusion processes, porosity, distribution of contaminant mass in matrix.**
- **Valuable to research efforts on contaminant fate, transport, biodegradation in areas away from TCH experiment.**
- **Use to conduct research on geophysical monitoring methods**

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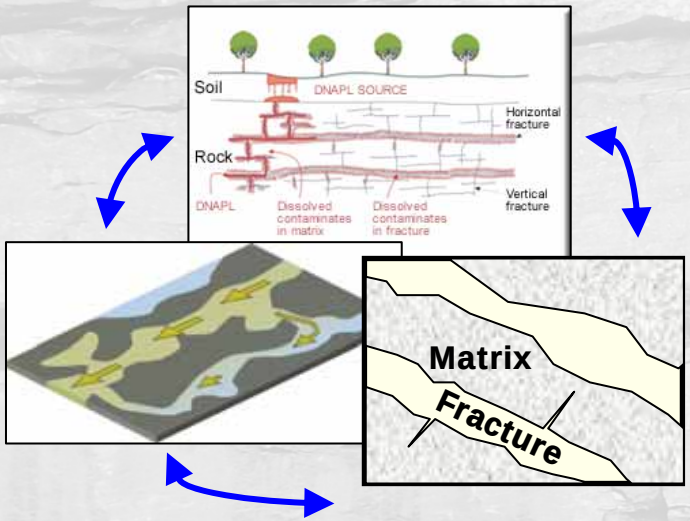
Research Priorities Focus on Unique Aspects...



- Fractures + Matrix
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...and Draw on Successful Approaches at Well-Established Toxics Sites

- Biogeochemical process understanding
- Gradients and interfaces

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