PRINCIPAUX ENJEUX LIÉS AUX AQUIFÈRES DE SOCLE

John M. Sharp, Jr.

Department of Geological Sciences

Jackson School of Geosciences

The University of Texas

Austin, Texas, USA

Uwe Troeger*

Lehrstuhl fuer Hydrogeologie

Technical University of Berlin

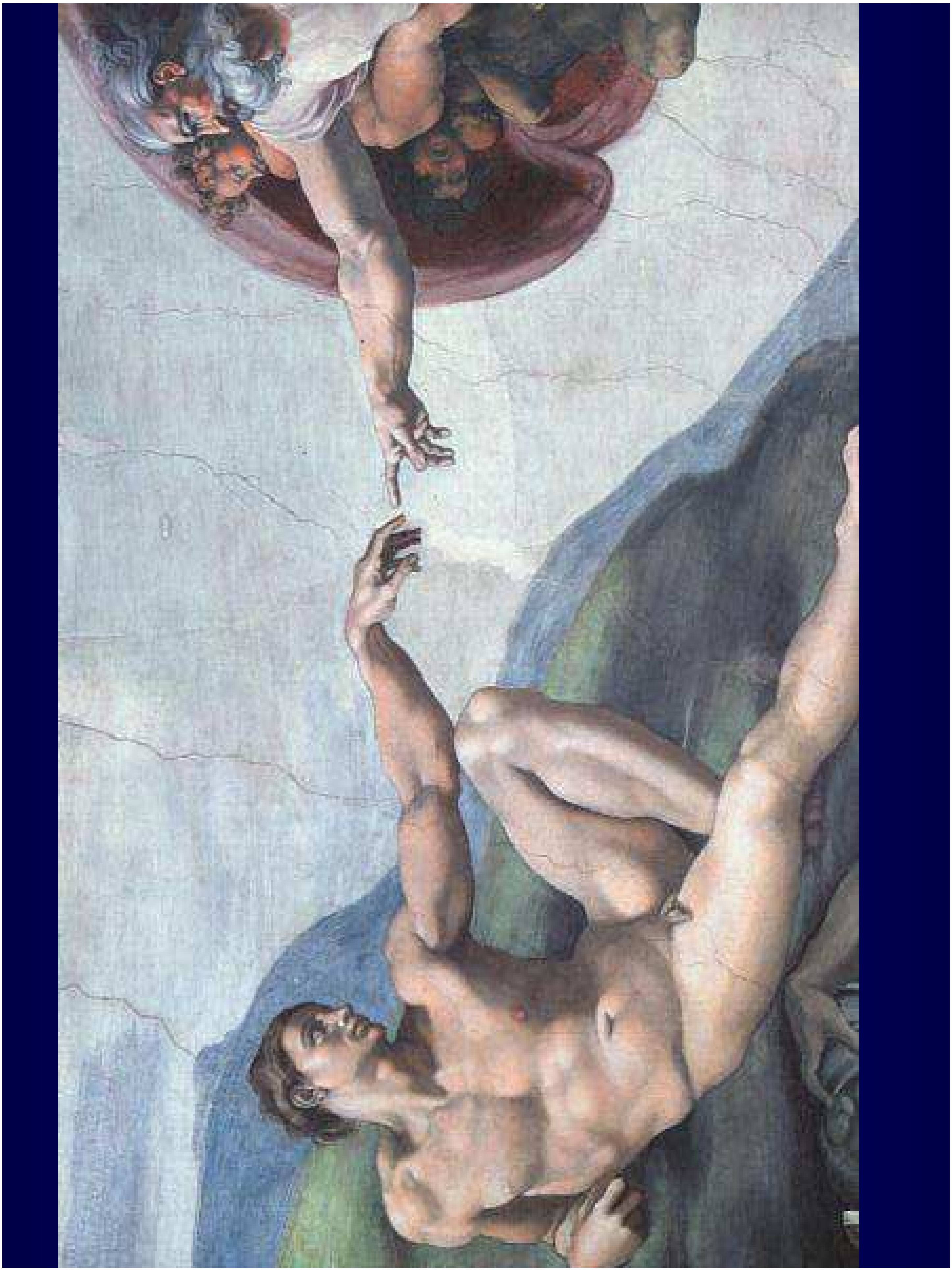
Berlin, Deutschland

* Chairman., IAH Network on Fractured Rock Hydrogeology

What is a hard-rock aquifer?

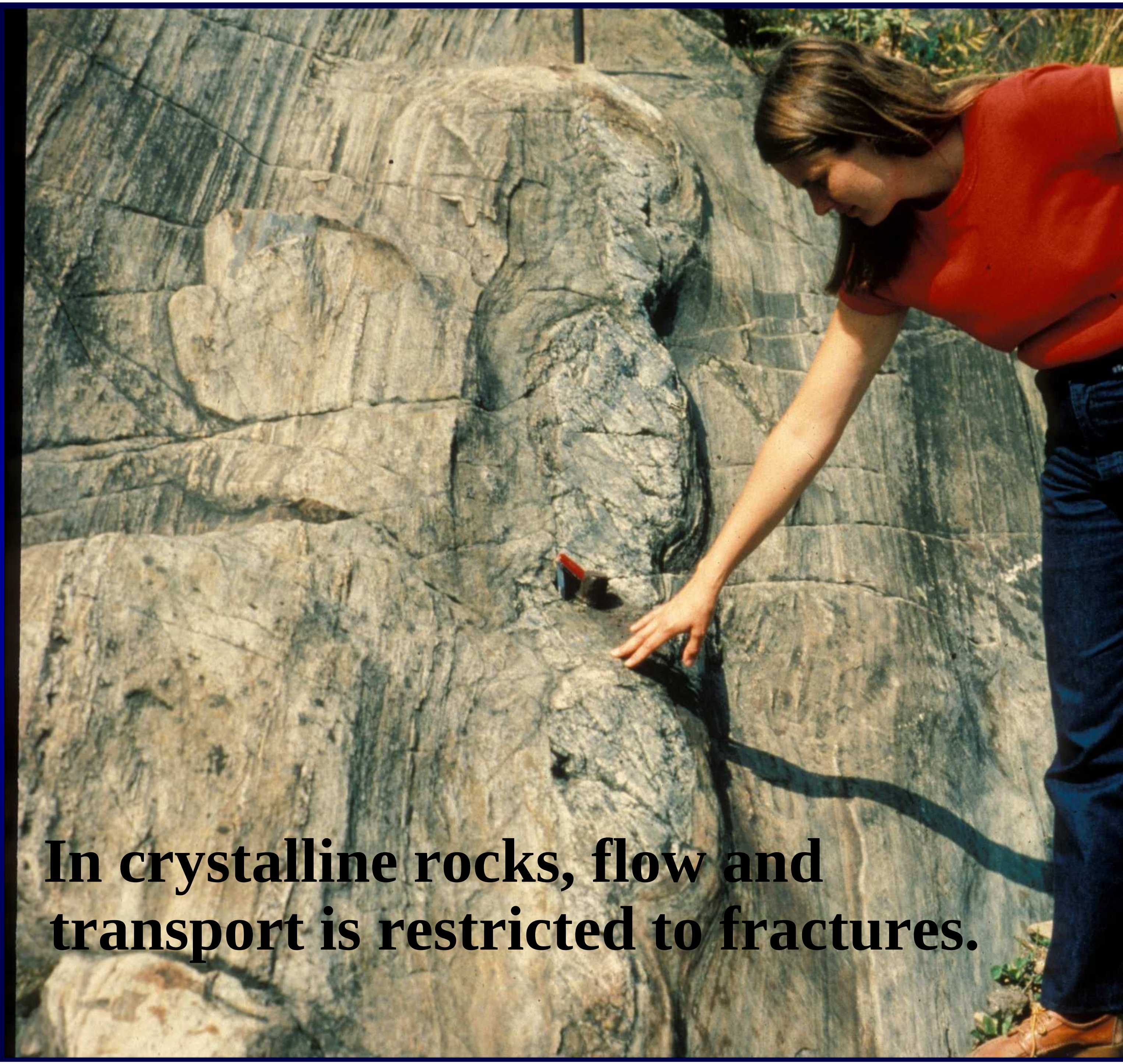
- Hard- rock aquifers occur primarily in fractured crystalline (igneous and metamorphic) rock systems and, in some cases, the overlying regolith.

- In hard-rock aquifers, fractures provide the major (or sole) permeability and, in many cases, the porosity and storativity.



FRACTURES CONTROL BOTH FLOW AND TRANSPORT IN "LOW PERMEABILITY" MEDIA

1. Production of:
   - Water (hard-rock aquifers)
   - Oil and gas
   - Geothermal energy (hot, dry rock)
2. Geotechnical/mining applications
3. Waste disposal (e.g., Sweden, Switzerland)
4. Many geological processes


In crystalline rocks, flow and
transport is restricted to fractures.

WHAT AQUIFERS ARE FRACTURED MEDIA?

- **All metamorphic rocks**
- **Almost all igneous rocks**

  Possible exceptions: some unwelded tuffs; vesicular basalts and their flow tops
- **Most sedimentary rocks**

  Possible exceptions: coquinas; poorly cemented coarse sandstones
- **Many unconsolidated deposits and soils**

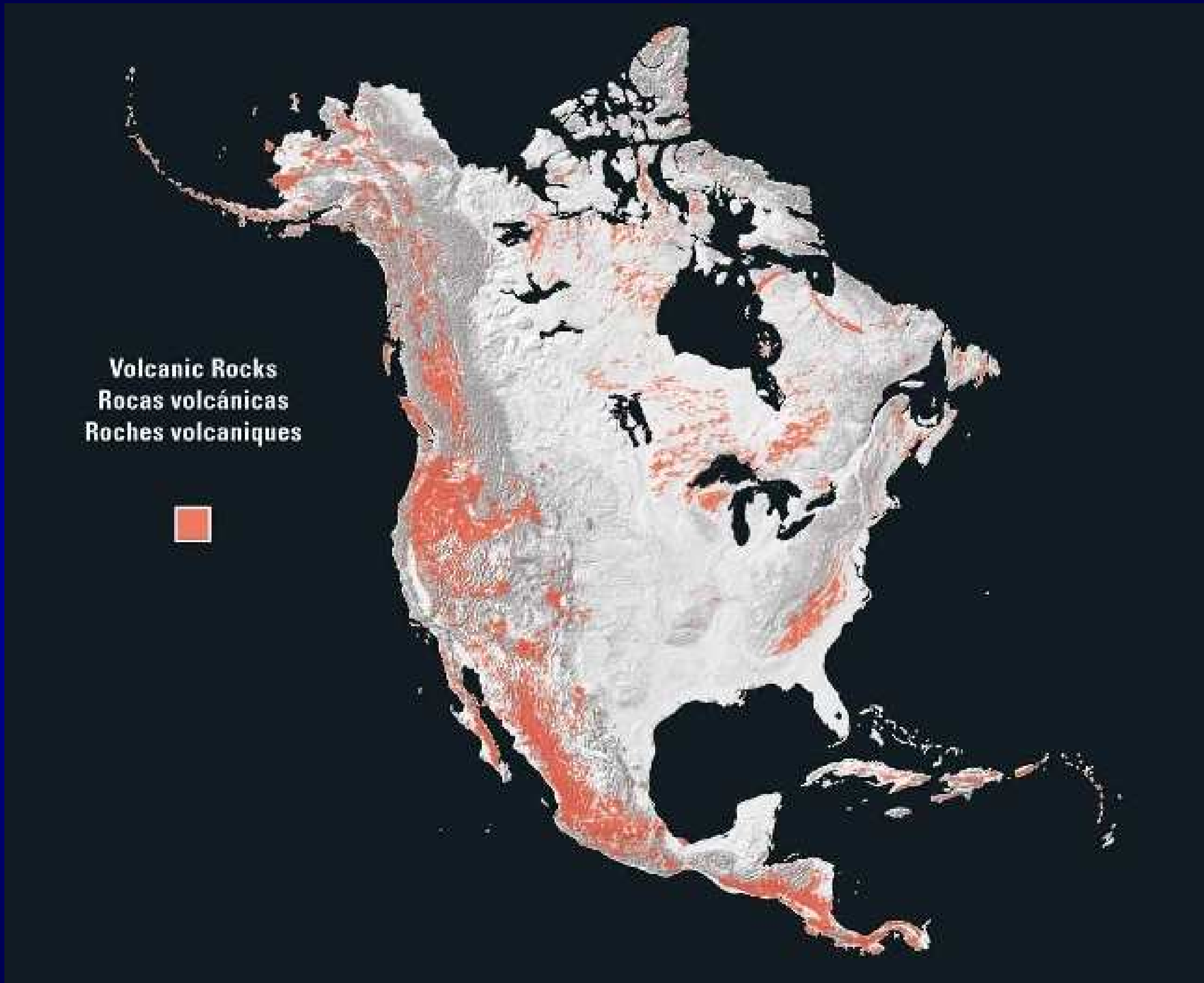
  Examples include: glacial tills, loess, and many soils

Fracture-dominated flow and transport are more the rule than the exception!

1. Hard-rock systems cover much of the Earth's land surface.

2. Hard-rock aquifers are the only reliable water resource in many of these areas.

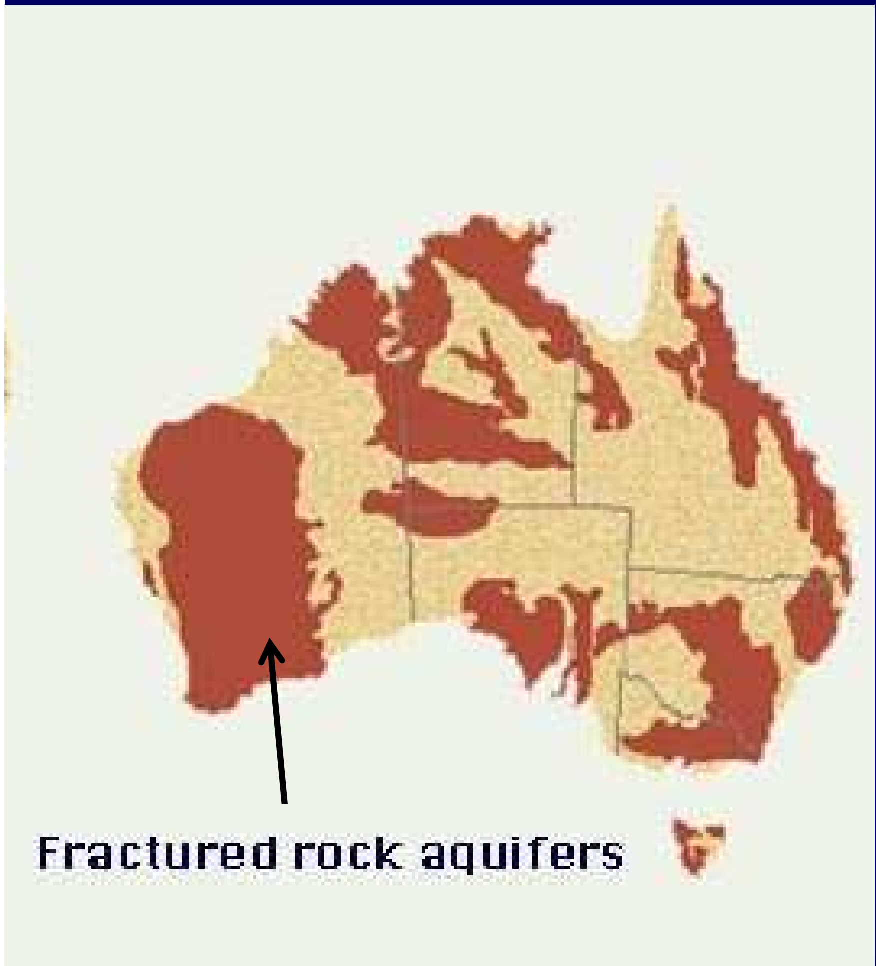
3. They underlie and interconnect shallower aquifers and sedimentary basins.

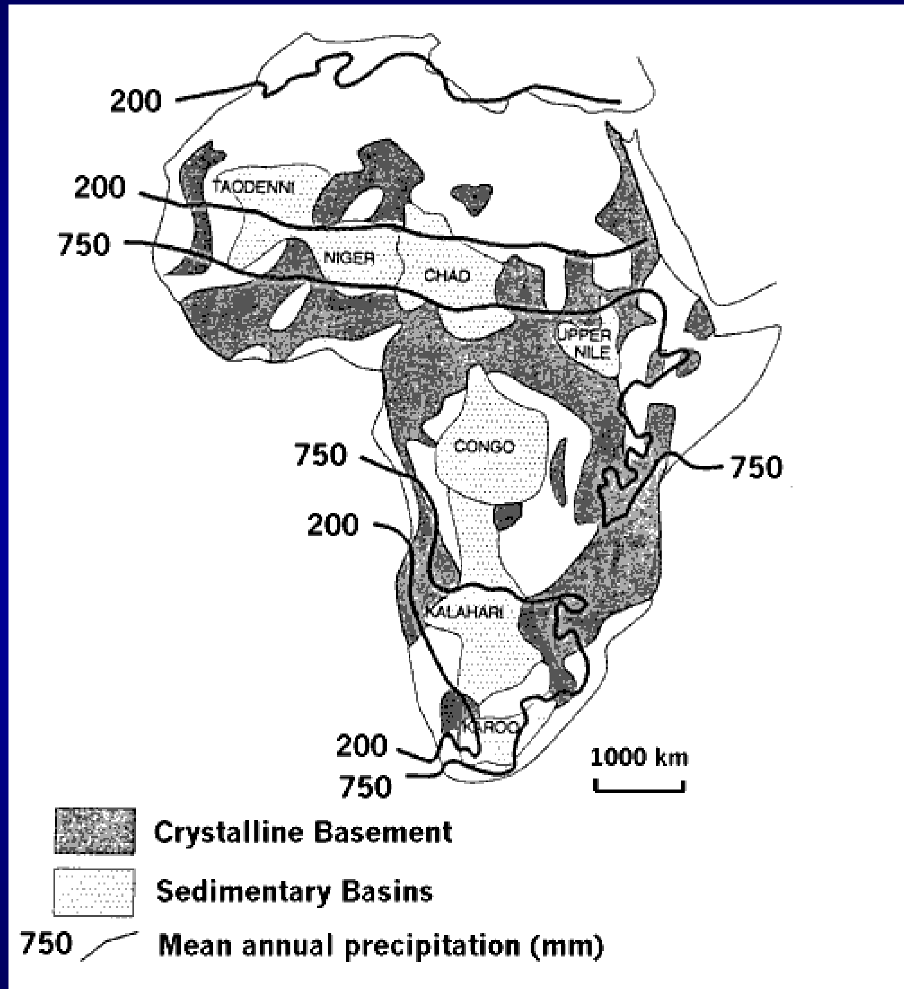


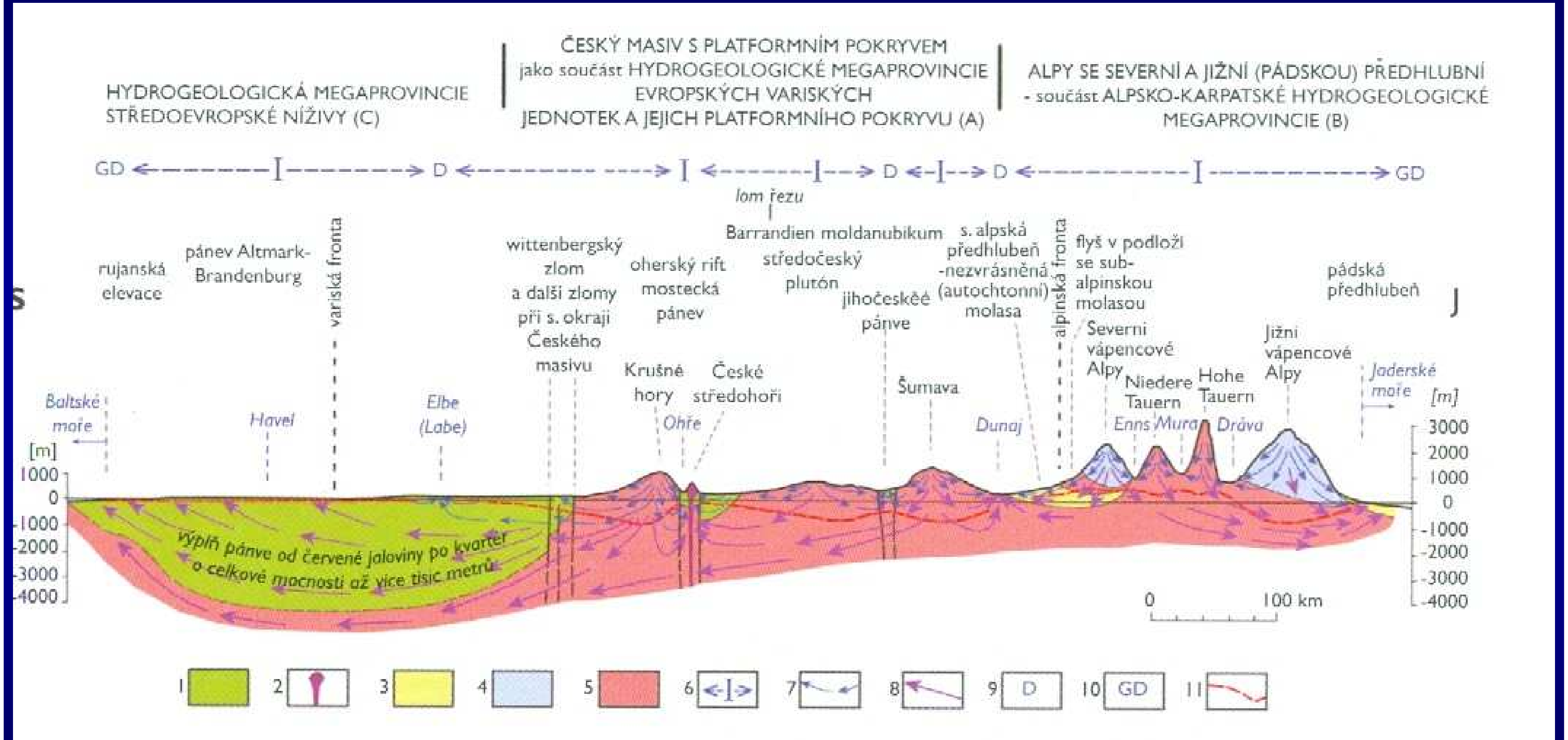
(U.S. Geological Survey, I-2781)

(U.S. Geological Survey, I-2781)

(U.S. Geological Survey, I-2781)


Fractured rock aquifers


200
200
750
TAODENNI
NIGER
CHAD
UPPER NILE
CONGO
KALAHARI
KAROO
750
200
750
200
750
1000 km
Crystalline Basement
Sedimentary Basins
750
Mean annual precipitation (mm)

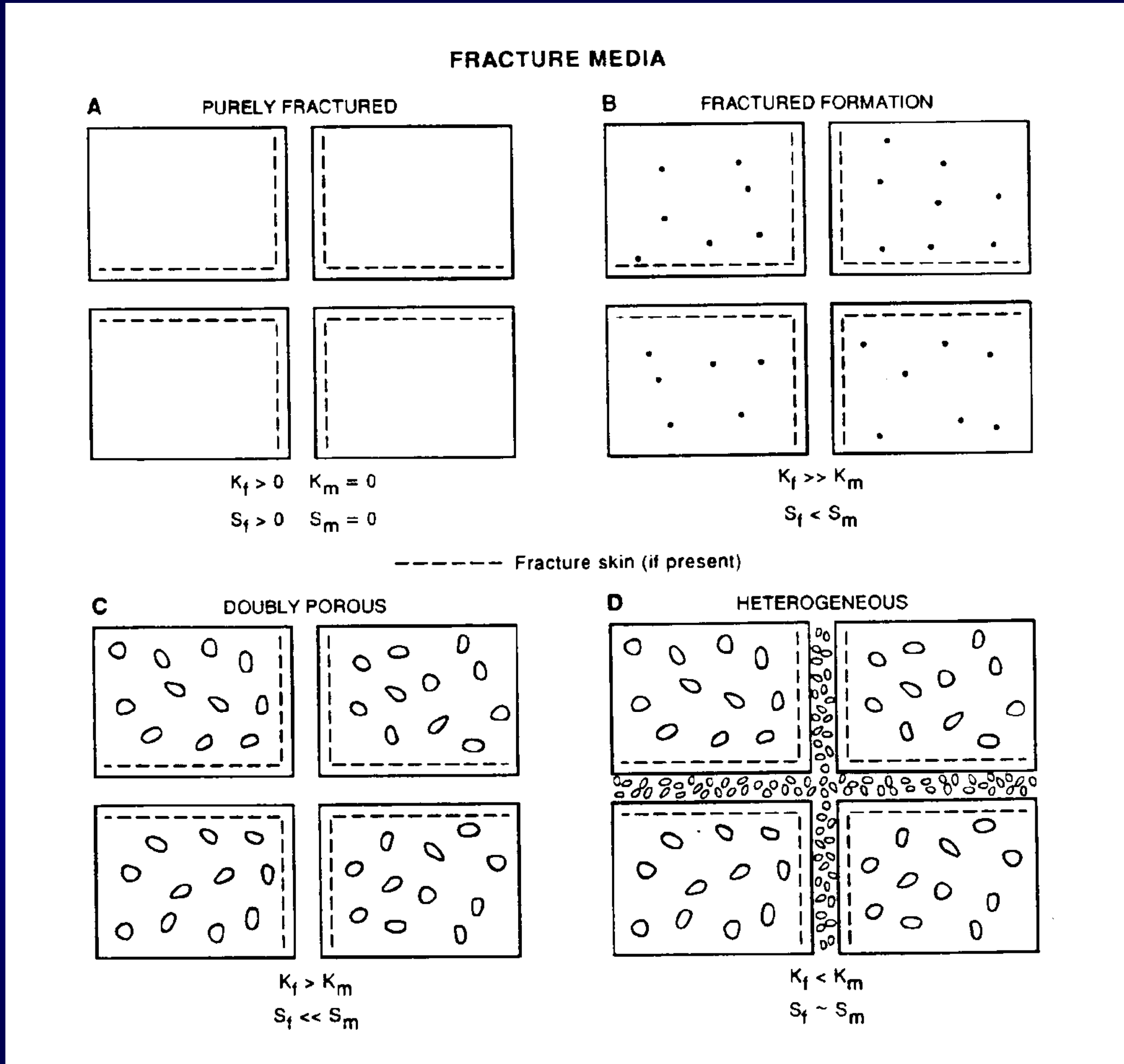


Krasny et al. (2014)

BLACK'S LAW

When dealing with fractured systems, we find that contaminants appear at places we don't expect and they appear faster than we had predicted.

John Black, IAH - Oslo, 1993



FRACTURE MEDIA
A
PURELY FRACTURED
$K_f > 0$ $K_m = 0$
$S_f > 0$ $S_m = 0$
B
FRACTURED FORMATION
$K_f >> K_m$
$S_f < S_m$
------ Fracture skin (if present)
C
DOUBLY POROUS
$K_f > K_m$
$S_f << S_m$
D
HETEROGENEOUS
$K_f < K_m$
$S_f \sim S_m$

FRACTURE CHARACTERIZATION

- Sets
- Orientation (strike and dip, if planar)
- Spacing [L] or density [L^{-1}]
- Aperture
- Roughness (asperities)
- Channeling
- Connectivity
- Skin properties

HYDROGEOLOGIC PARAMETERS

- Permeability (tensor)
- Porosity (scalar)
- Effective porosity (scalar or tensor)
- Skin properties
  - Permeability
  - Porosity
  - Sorptivity
  - Diffusion coefficient

Note: These parameters may vary *in space*, over time, and *with groundwater flow*.

What is a fracture skin?

Fracture skins are:

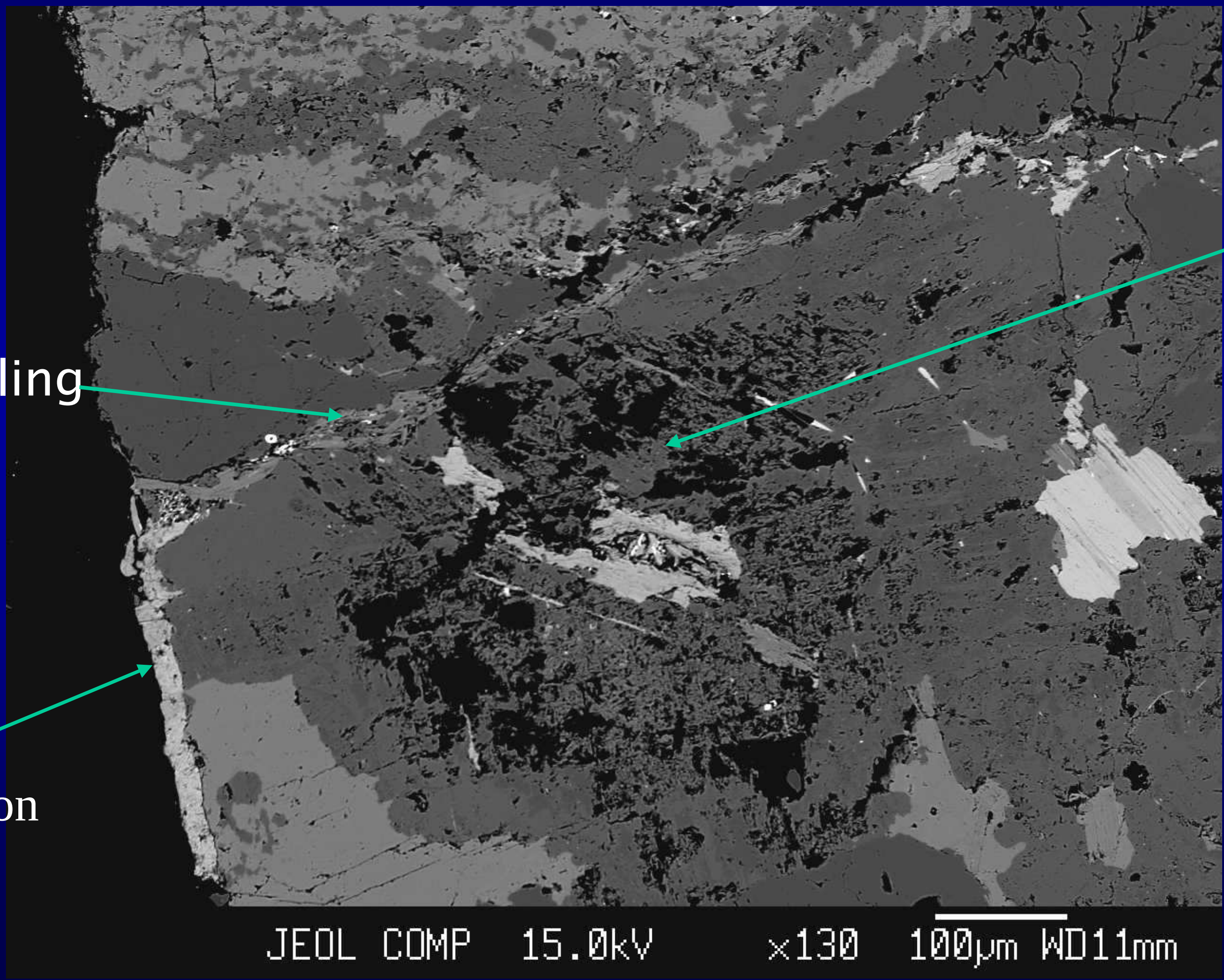
"zones of altered rock abutting a fracture surface and the coatings of the fracture surface by infiltered debris, precipitated minerals, and organic matter."

Robinson and Sharp, 1997

Increased weathering occurs along fractures in granite because of a damage zone of microfractures and weathering processes.

The alteration zones are evident in this granite.

Skin Development in Elberton Granites

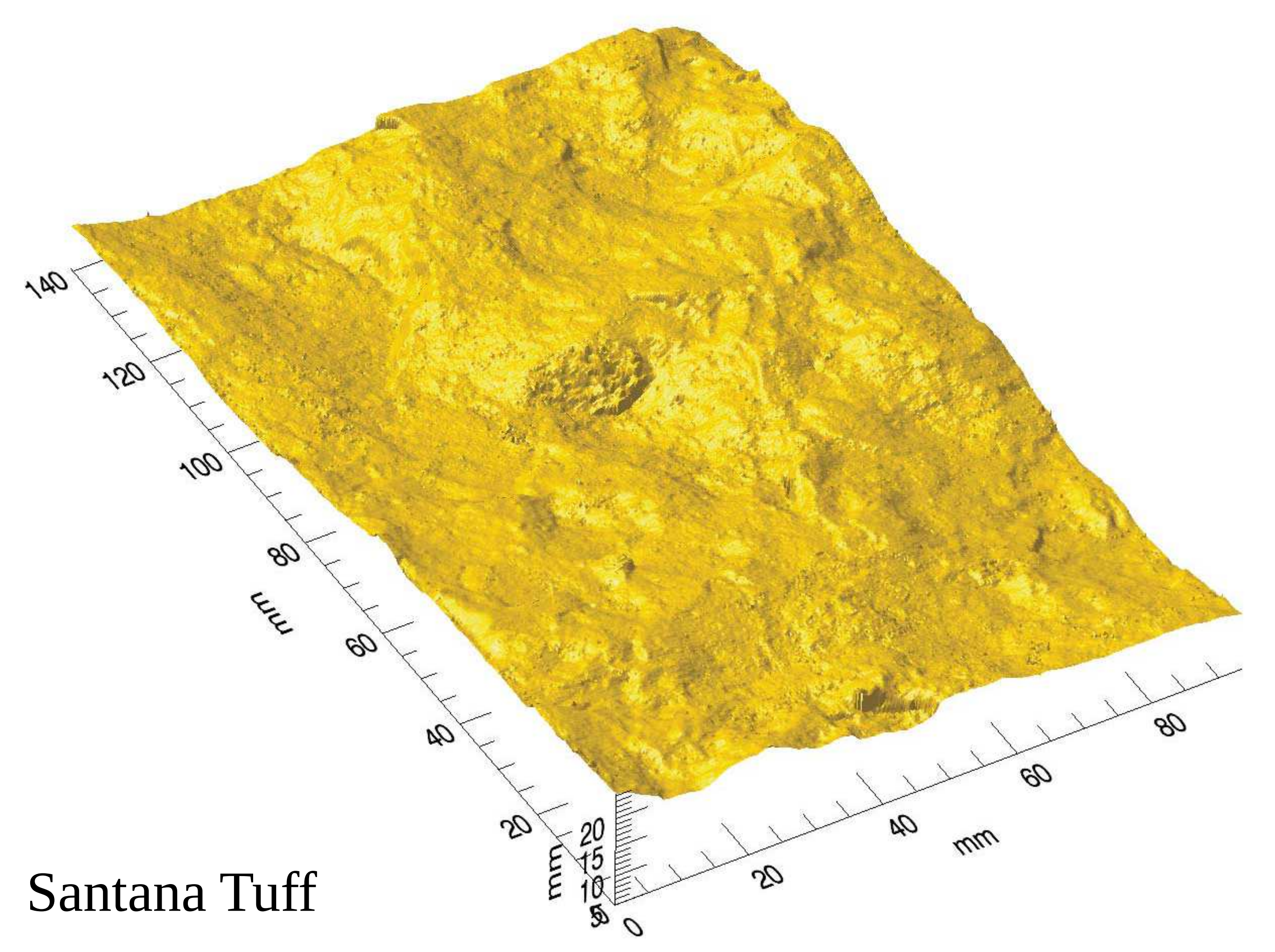


Garner, U.T. Ph.D. , 2007

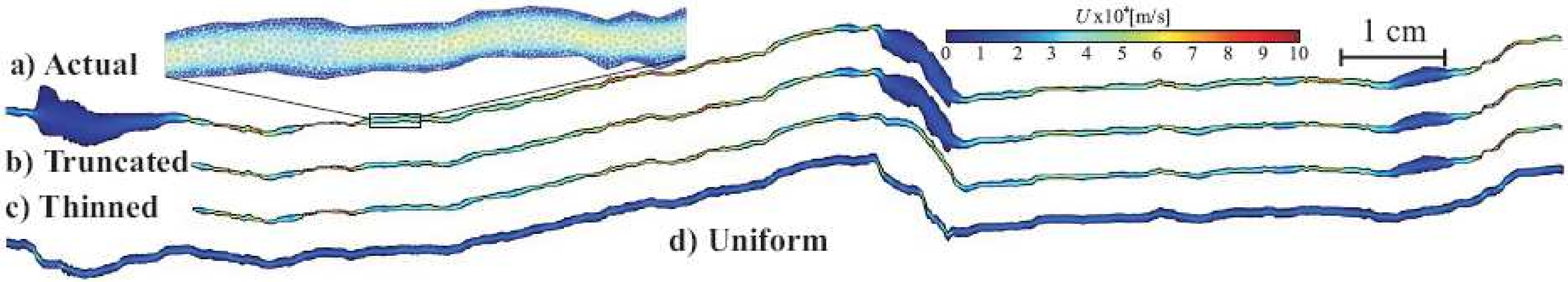
Importance?

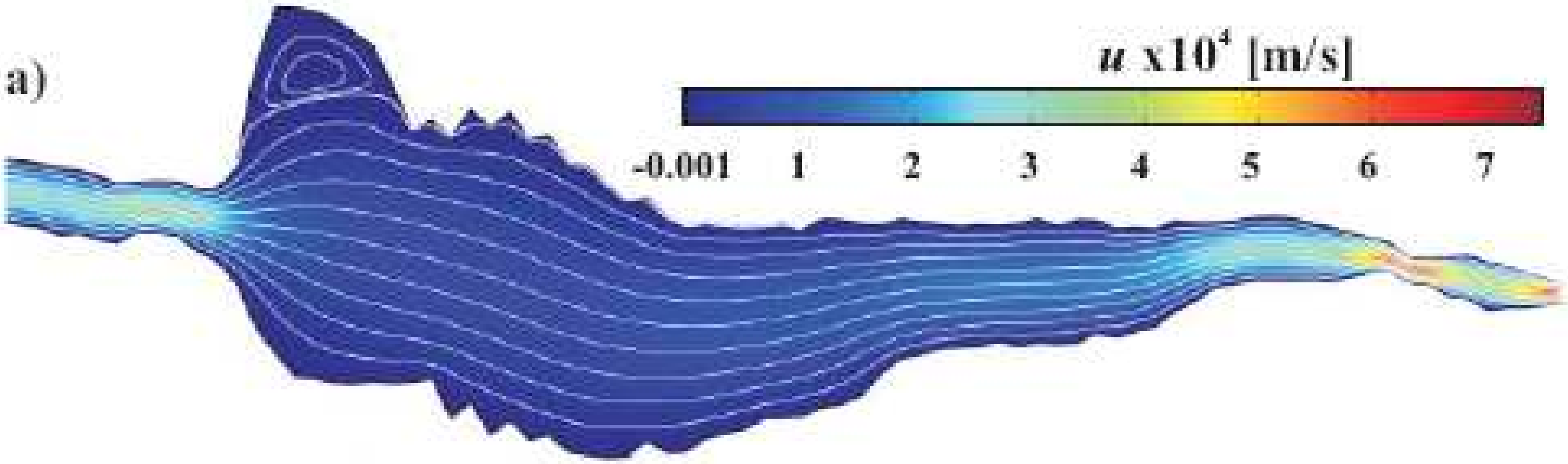
- Flow and transport in many systems is fracture controlled.
- Skins may have a significant effect on:
  - Rates of solute (including pollutant) transport.
  - The length of time a fractured rock system will retain the solute.
- Black's Law

What does a fracture look like?



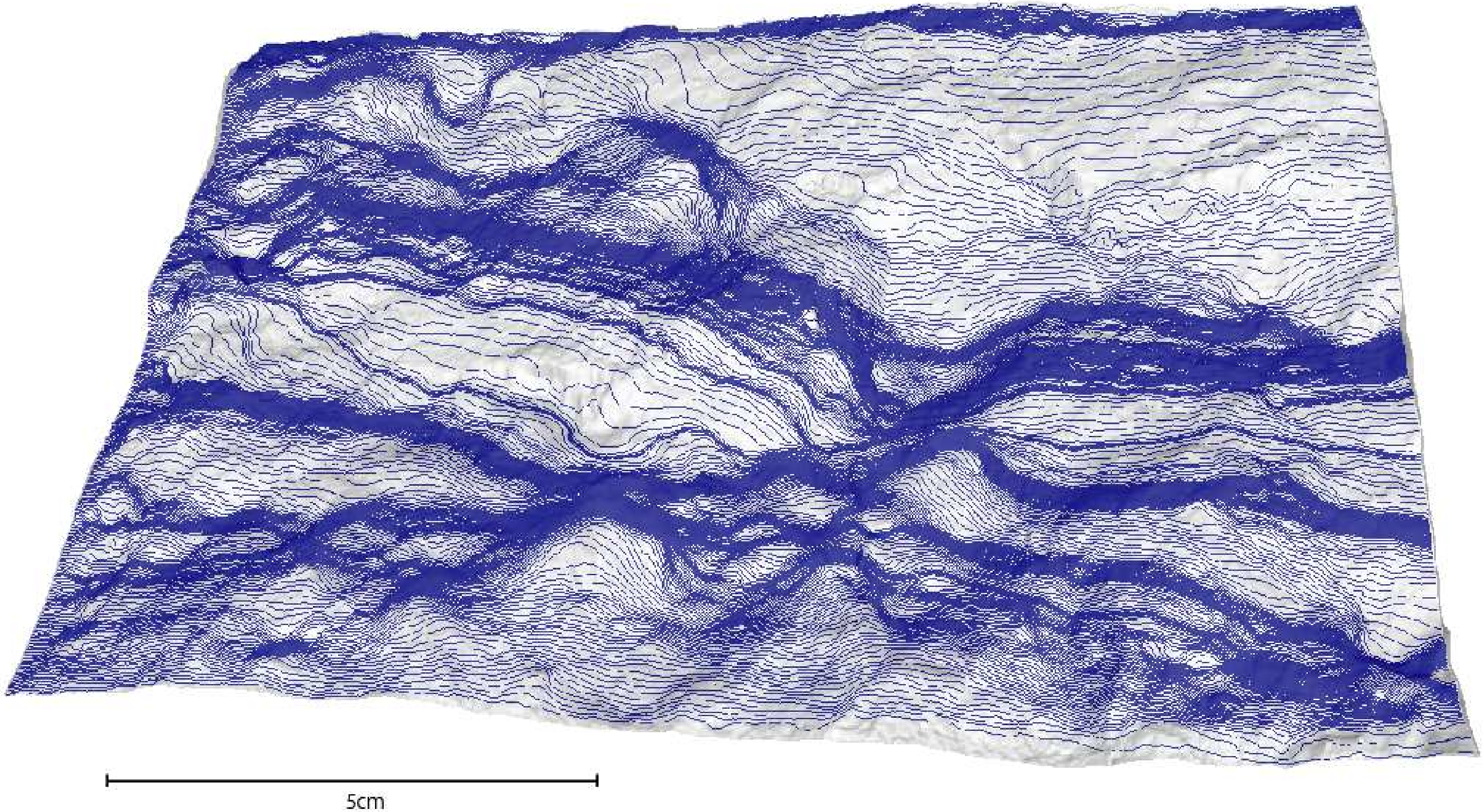
Cue movie





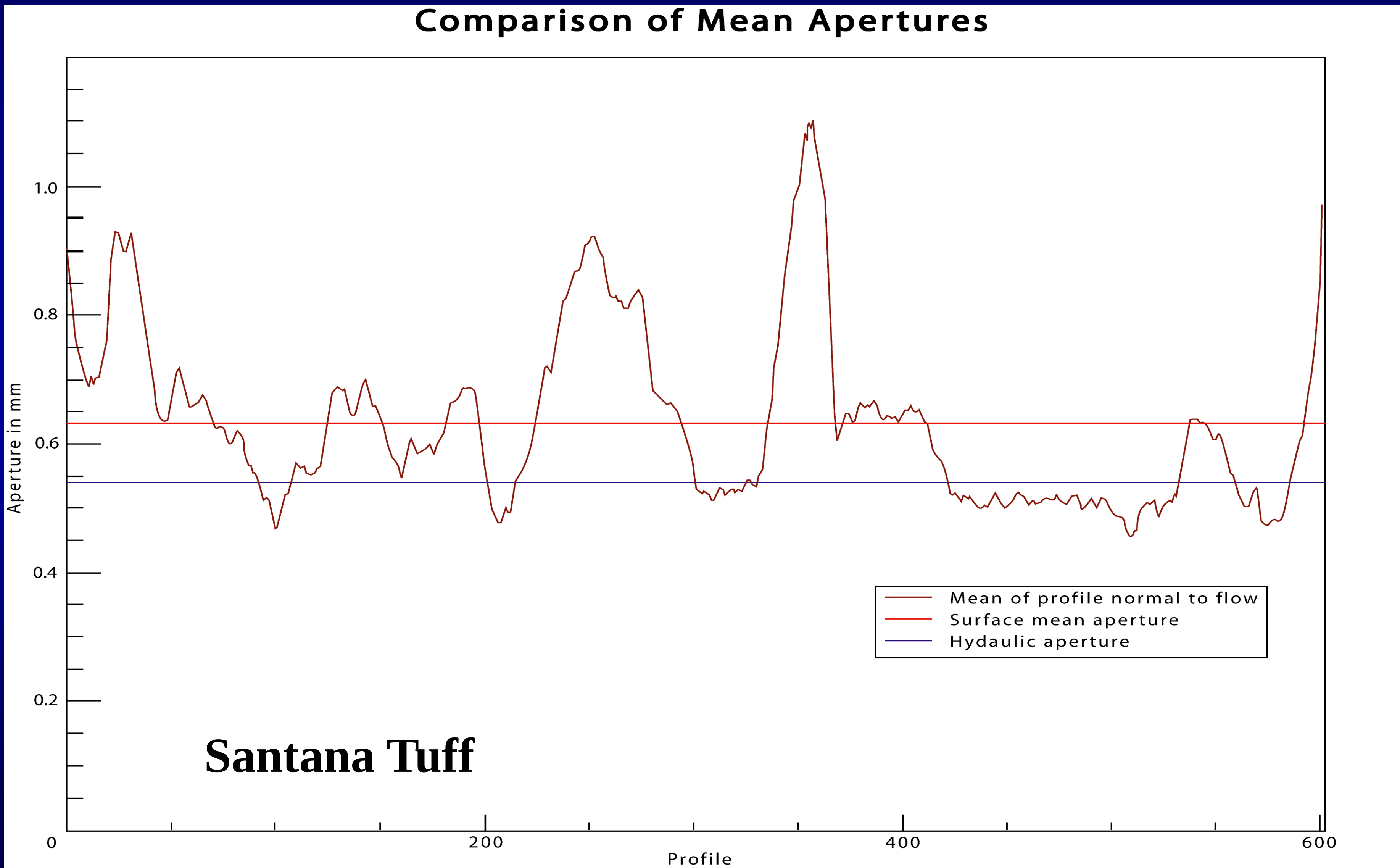
Cardenas et al, 2008

What does a fracture look like?

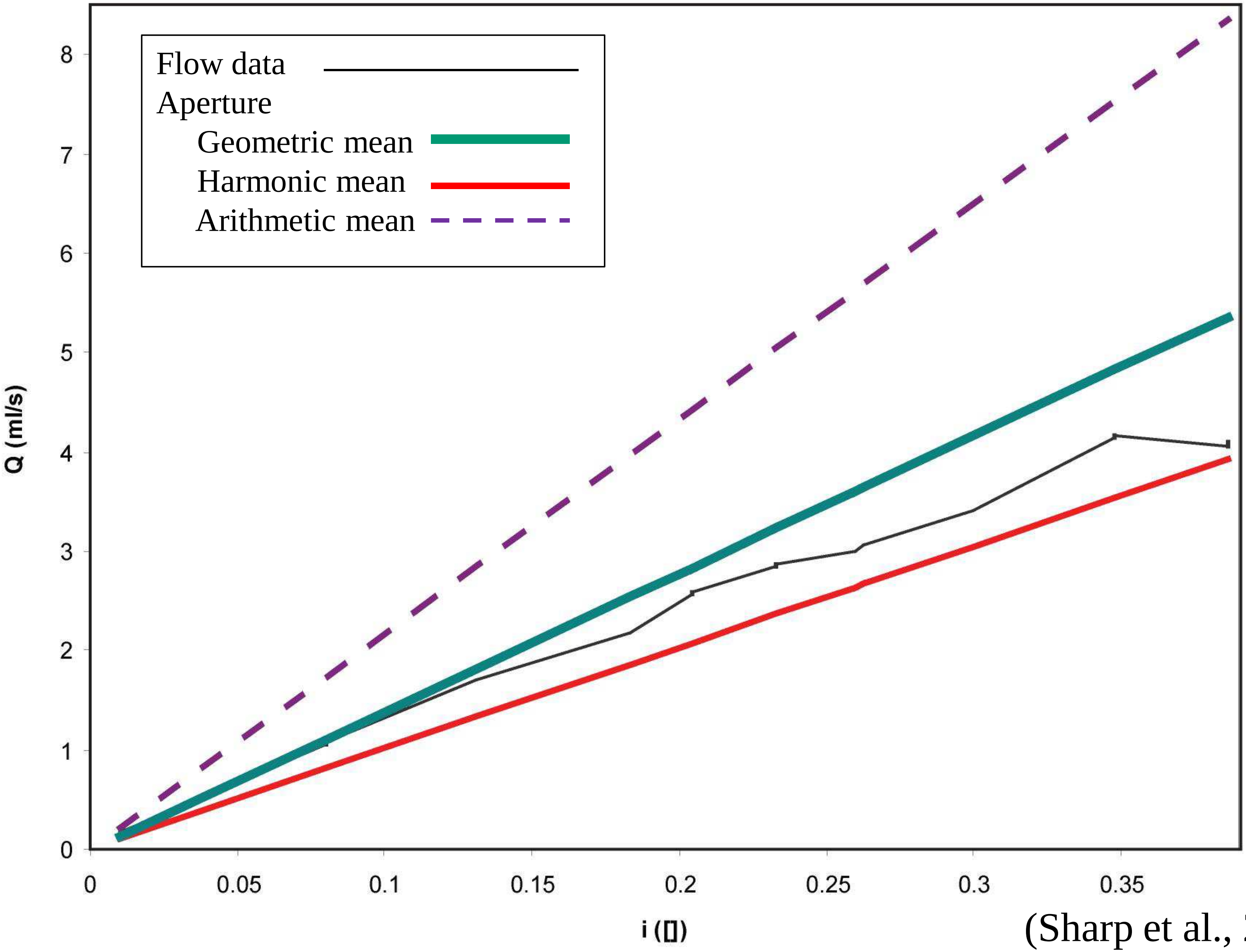


Particle Tracks for CC02-2

PERMEABILITY - Which aperture?

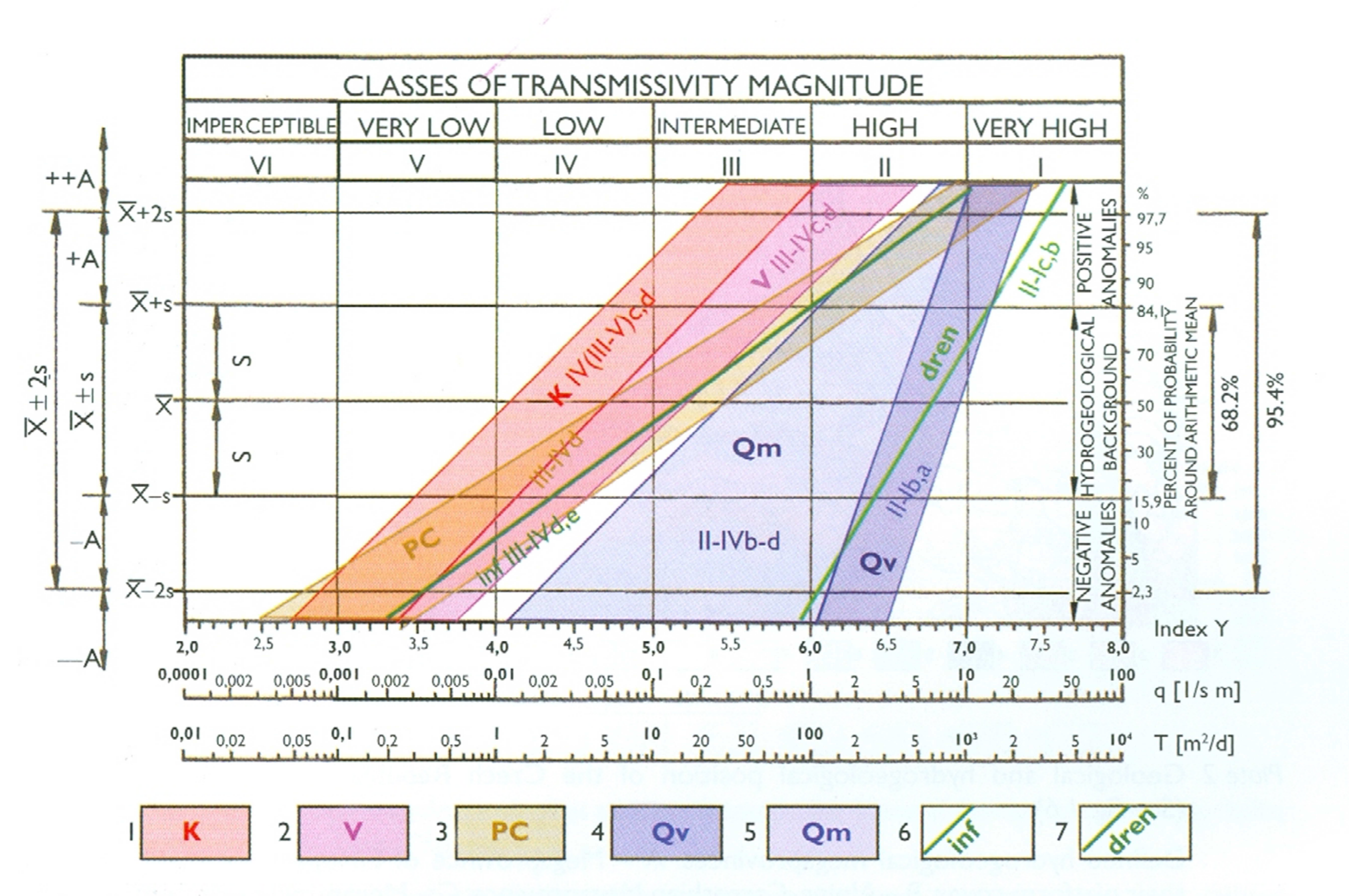


CC02-2 Comparison of Means



(Sharp et al., 2014)

TRANSMISSIVITY



Krasny et al. (2014)

VERTICAL ZONATION

Upper / local (weathered) zone

- If present, the most productive zone

Middle zone (regional)

- 10s -100s m – k decreases with depth
- 100 m “rule”

Lower (retarded flow) zone

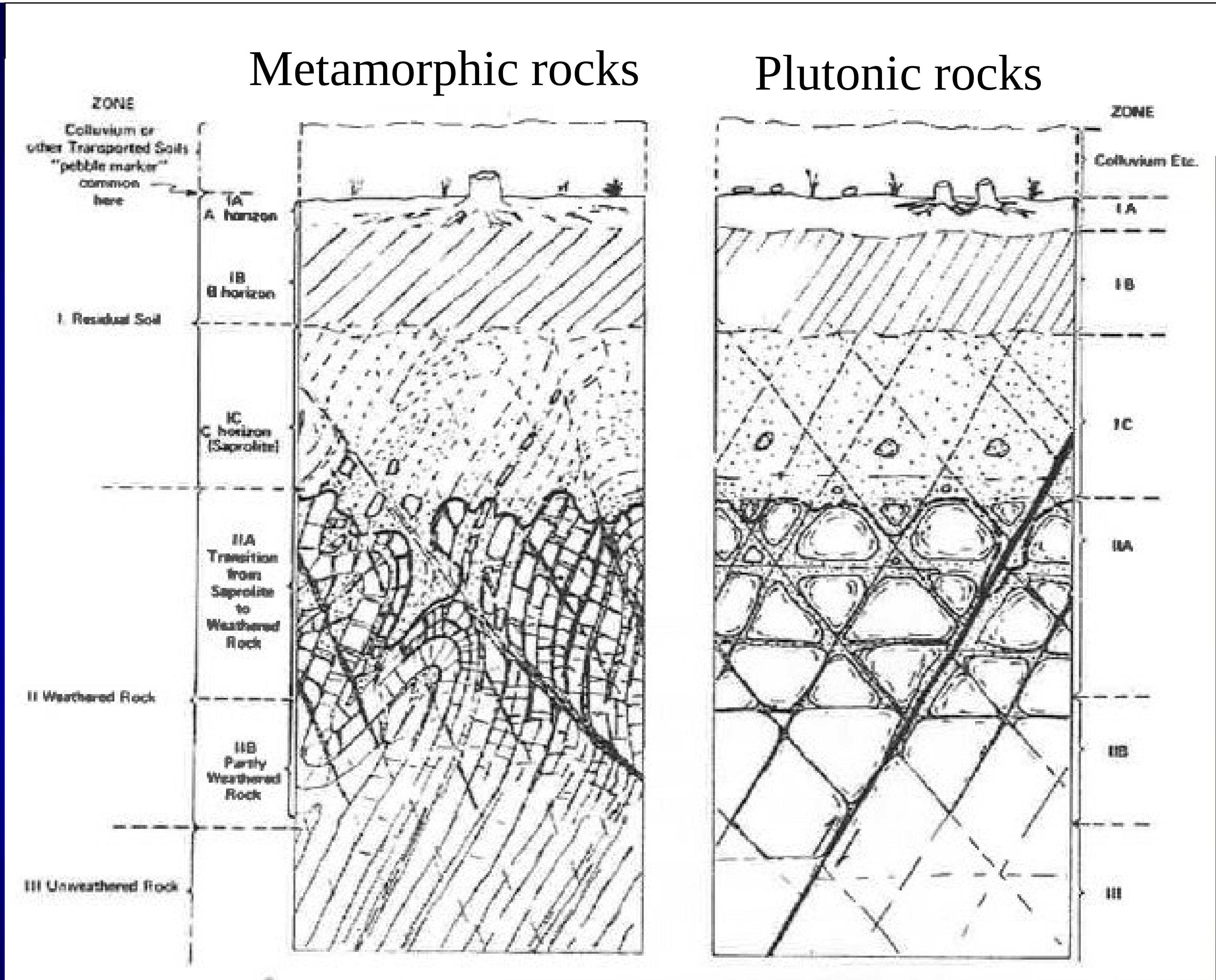
- Flow in isolated fracture zones
- Sometimes surprisingly high

General vertical zonation

(modified from Krasny et al., 2014, and Deere & Patton,1971)

HYDRODYAMICAL ZONE (Krasny & Sharp)	**ZONE (Deere & Patton)**		**Depth [m]**	**Description**	**Relative permeabilty**	**TDS (g/L)**	**Hydrochemical facies**	**RQD % (NX core)**	**Core recovery % (NX core)**
Upper / local (intensive / shallow)	I Residual soil	Ia O, A, & E soil horizons	zero to tens of m	top soil, roots,organic matter; zone of leaching and eluviation	low to medium	0.0x to 0.x	Ca (-Mg)-HCO3(-SO4)	-	0
		Ib B soil horizon		clay-enriched; accumulations of Fe, Al, & Si; may be cemented; no relict strctures	LOW			-	0
		Ic C horizon (saprolite)		relict rock structures retained; fines are silts grading to sands; < 10% core stones; often micaceous	medium			0 or not applicable	generally 0-10%
	II Weathered rock	IIa transition		Water losses high during drilling; relict rock structures retained; fines are commonly fine to coarse sand; grus; 10-95% core stones; spheroidal weathering common	HIGH			variable, 0-50%	variable, 10-90%
		IIb partly weathered		joints stained to altred, some alteration of feldspars and micas	medium to high			generally 50-75%	generally > 90%
Middle / regional (intermediate)	III Unweathered rock		hundreds of m	No iron stains along joints, little weathering of feldspars and micas	low to medium	up to several g/L	Na-HCO3(-SO4)	> 75% generally > 90%	nearly 100%
Lower / retarded (slow, deep, negligible down to stagnant)			many thousands of m		low	up to several hundreds g/L	Na_CL		
Global (often insignificant)					very low		Na(-Ca)-Cl		

Note: See table in abstract.



Deere & Patton (1971)

CHALLENGES

- How to characterize and parameterize these very inhomogeneous systems.
- Upscaling from lab-to-well field or from well field-to-regional scales.
- Finding appropriate data to validate or test numerical models of fracture system hydrogeology and transport of solutes, colloids, and heat.

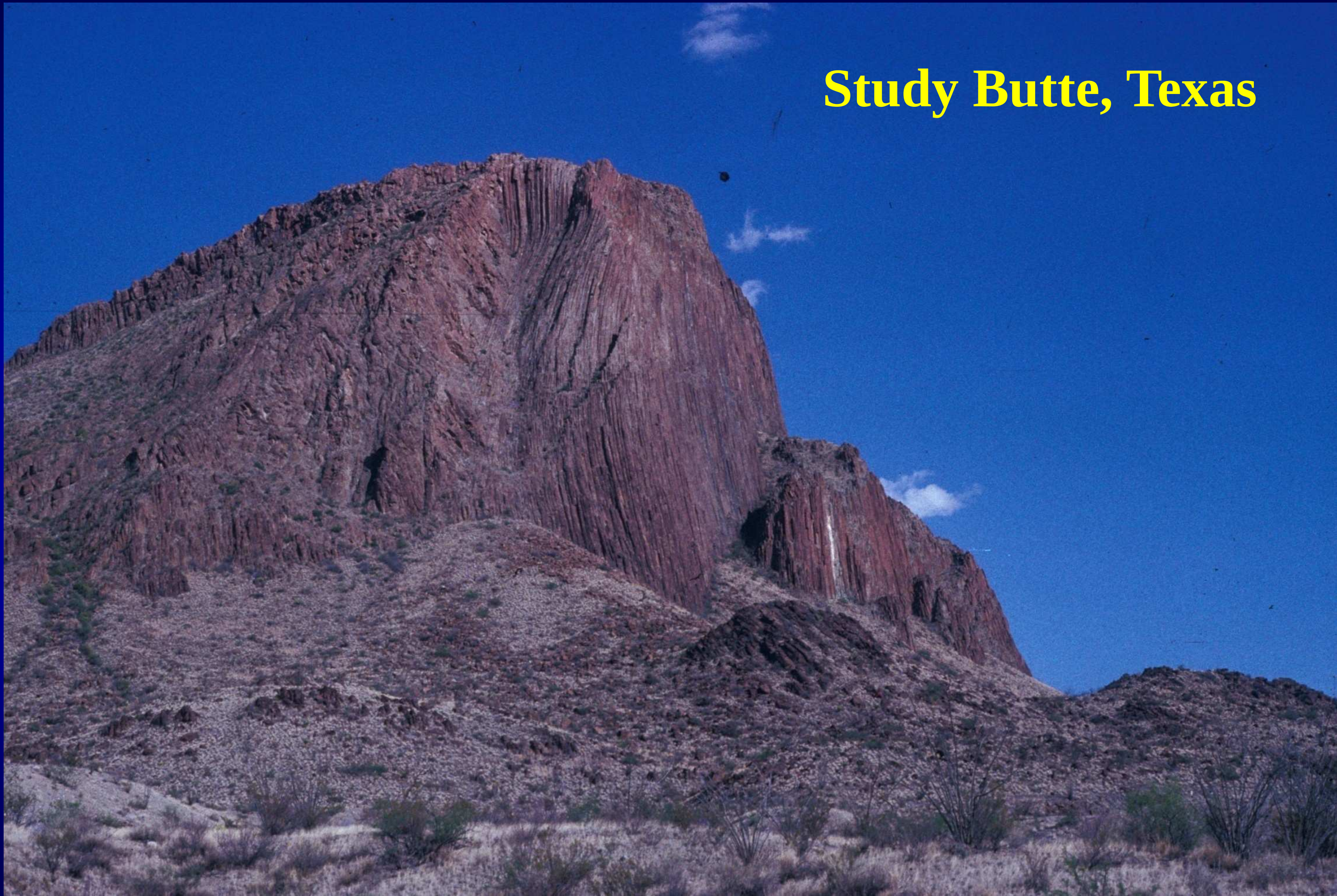
QUESTION

- Is fractured rock hydrology so complex that there is little hope of making significant advances?

Cliff Voss, 2003, Hydrogeology Journal, v. 11, p. 415-417

Comment on Voss' question

- More field, laboratory, and modeling studies are needed.
- New techniques are being developed.
- We need more data and case studies.
- Conferences like this one should point to promising new research directions and applications.
- **There is definitely the potential to make significant advances**.


Study Butte, Texas

la fin!

sheeting joints, Missouri

GYPSUM-FILLED FRACTURES **OPEN FRACTURES**

Loess bluff
Glasgow, Missouri