CRYSTALLINE ROCK AQUIFERS
THE LLANO UPLIFT
CENTRAL TEXAS, USA

Early Career Hydrogeologists' Network

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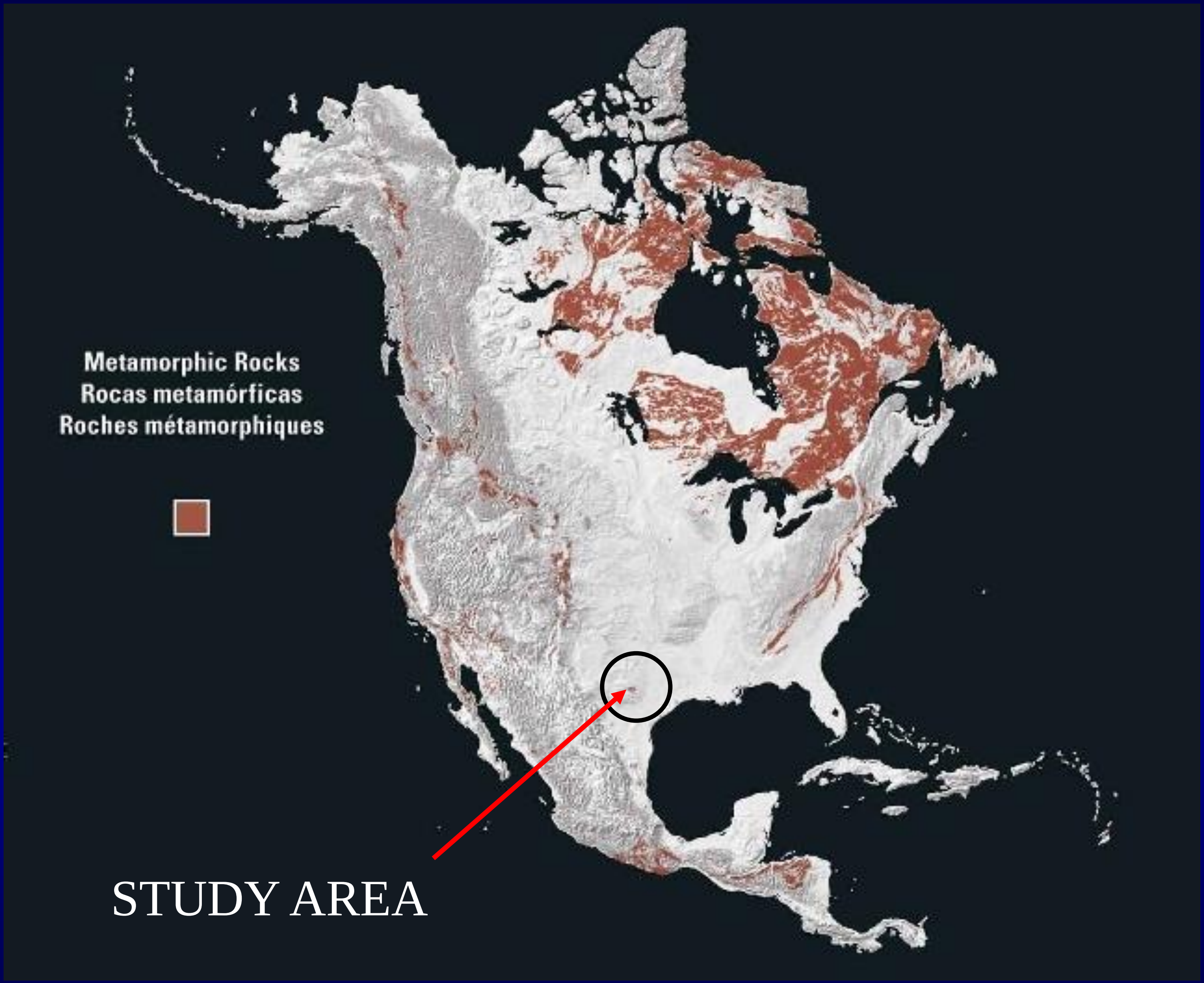
Hard-rock systems cover much of the Earth's land surface & in many of these areas, like study area - the Llano Uplift,

1. They are only reliable (and locally available) water resource and

2. They underlie, abut, and interconnect other shallow aquifers.

Purpose

To characterize crystalline rock aquifers through a study of hydraulic properties of the aquifer on a macro scale through well yields and vertical zonation and the micro scale through fracture skin properties.



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

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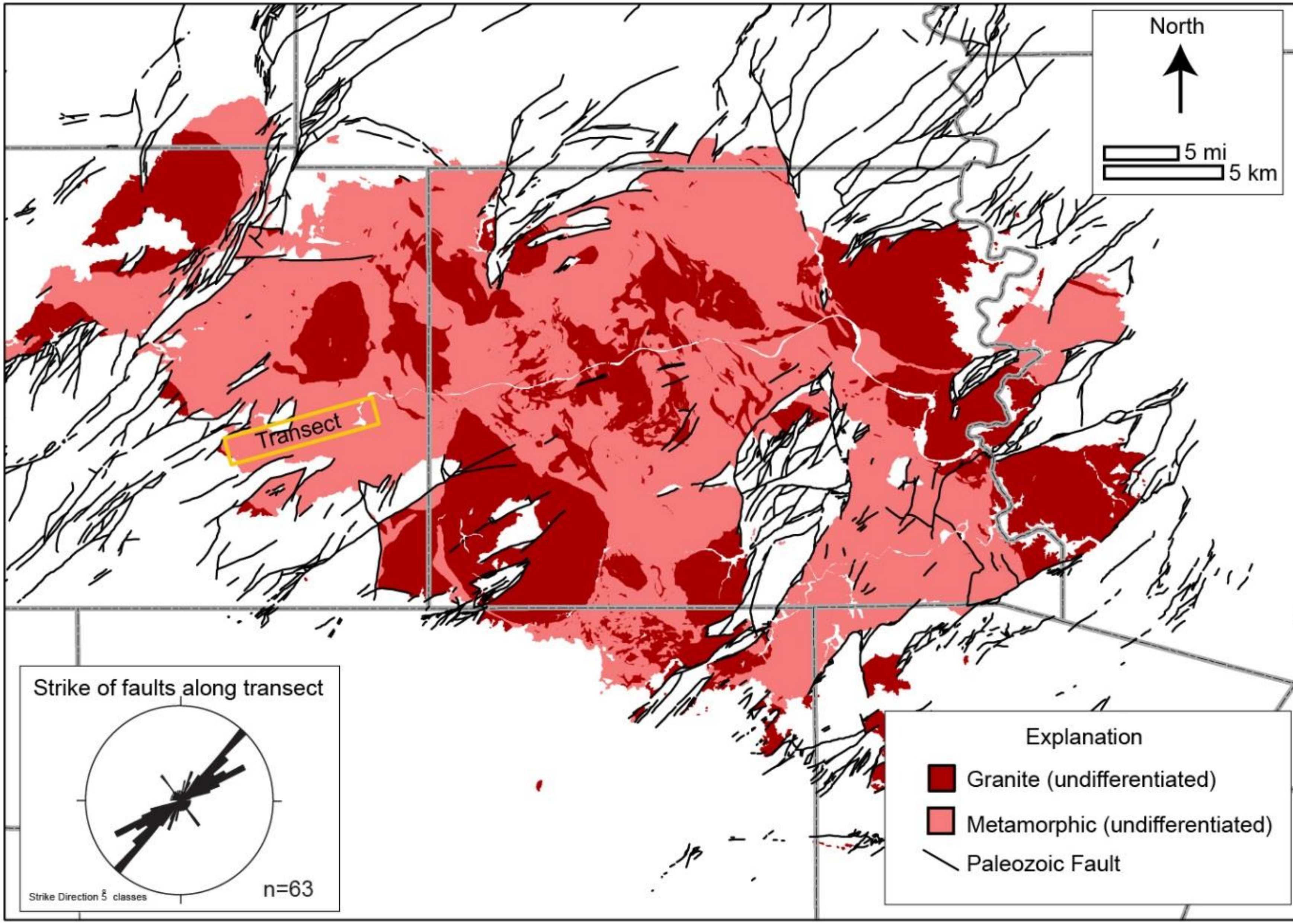


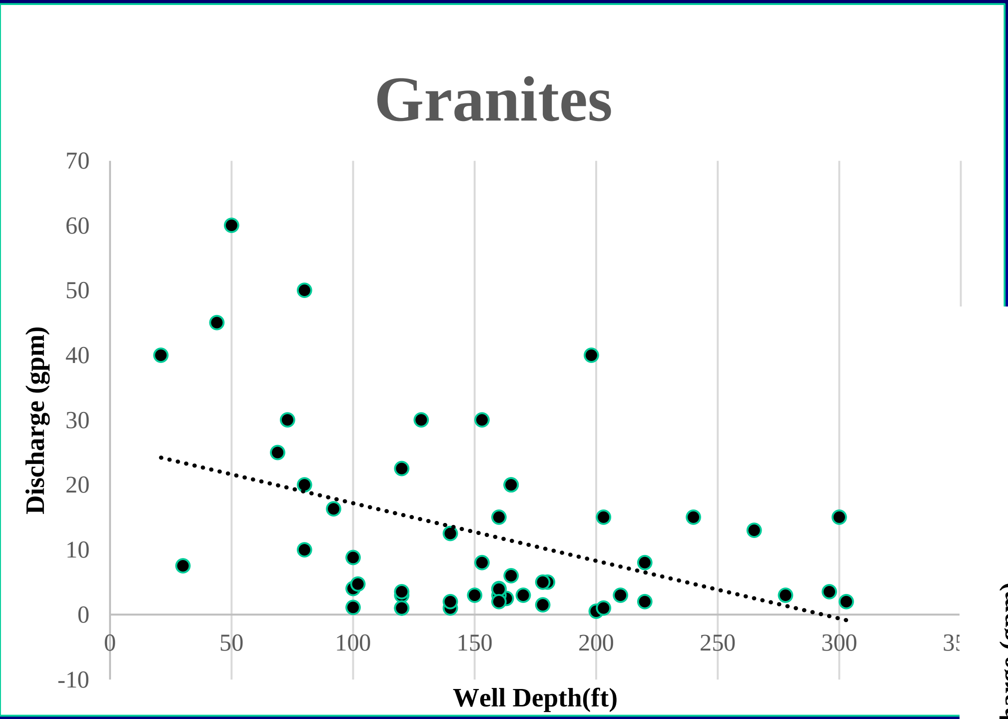
Modified from Hunt (2008)

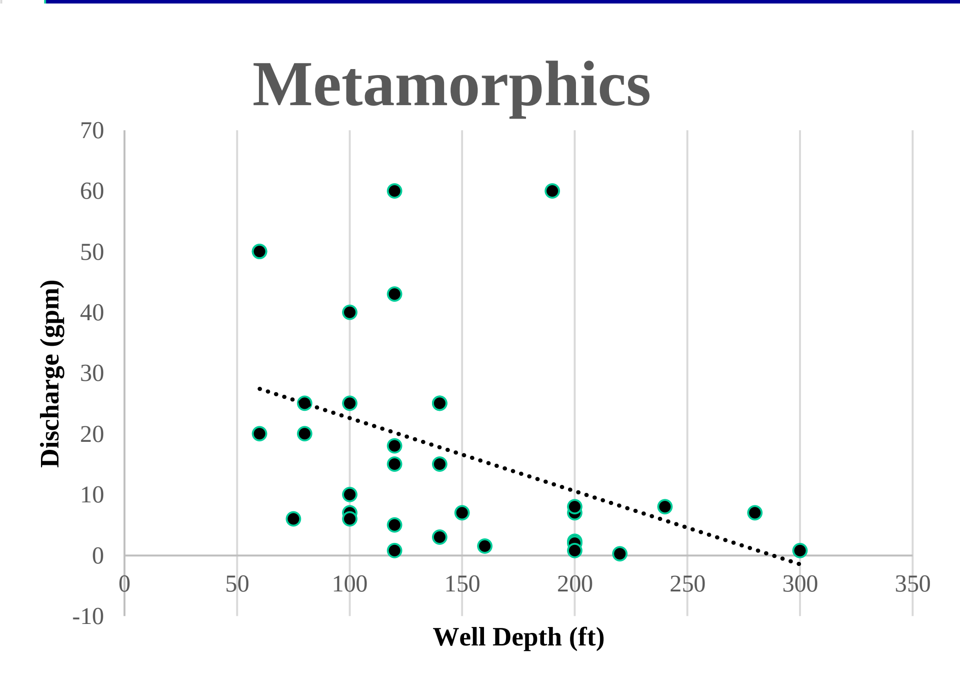
WELL YIELDS FROM DRILLERS' LOGS

(Mostly from TWDB files)

Rock type (number of wells)	Median well yield [L/s]	Median well depth [m]	Median water table depth [m]	Median regolith thickness [m]	Reference
Granite (197)	0.50	22.9	-	-	Landers & Turk, 1973
Grus (103)	1.01	12.2	-	-	"
Fractured granite (40)	0.38	25.9	-	-	"
Schist (73)	0.25	15.8	-	-	"
Gneiss (48)	0.25	24.1	-	-	"
Granite (559)	0.95	35.1	-	11.9	Hunt, 2008
Schist/gneiss (537)	0.50	42.7	-	5.5	"
Granite (566)	0.50	48.8	11.0	7.0	TDWB, wells since 2008
Schist/gneiss (278)	0.44	42.7	11.6	6.7	"

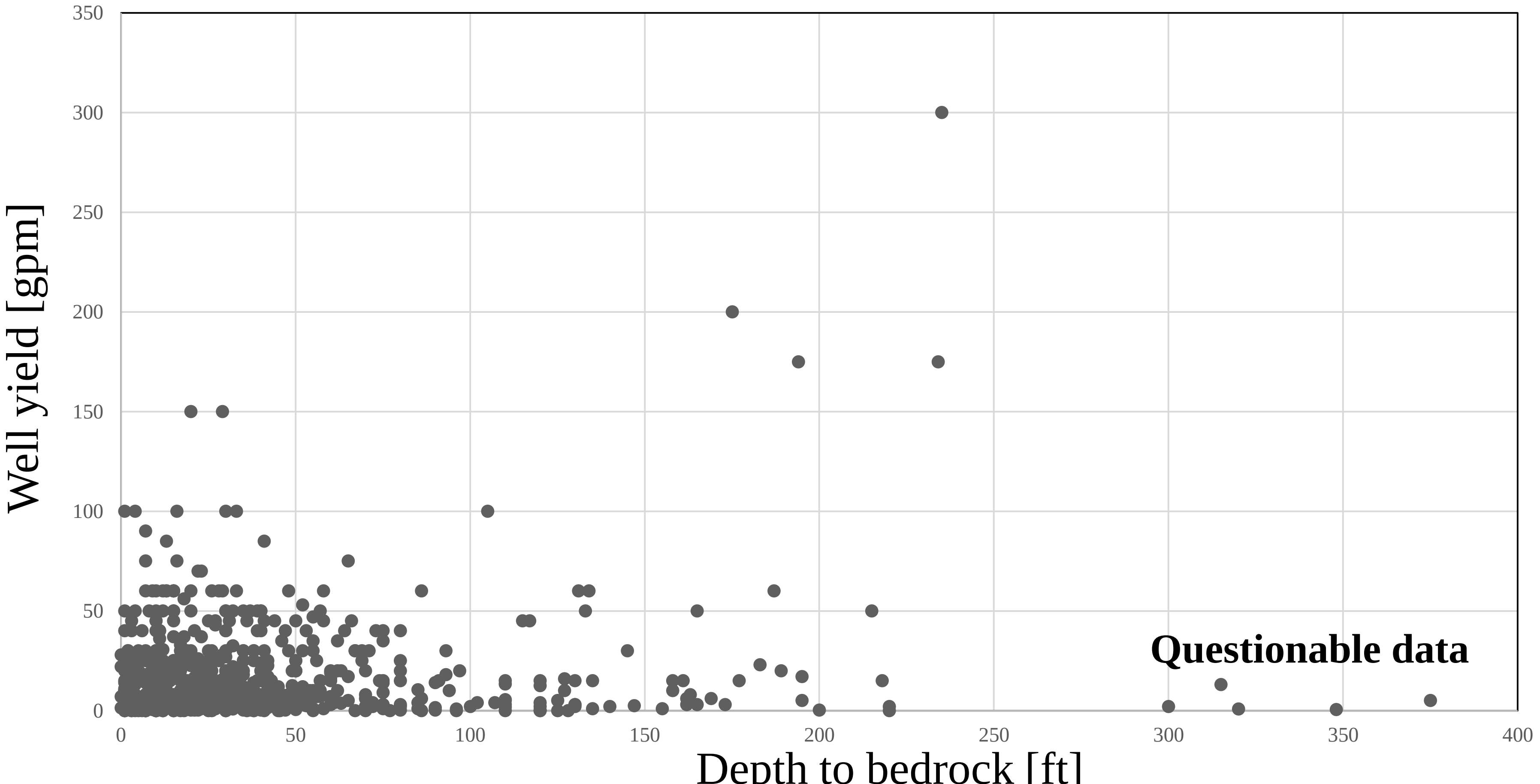
Mason County
Discharge [gpm] versus well depth [ft]





100 gpm = 6.3 L/sec = 6.4×10^{-5} m^3/sec

Llano & Mason Counties
Well yields [gpm] versus regolith thickness [ft]



100 gpm = 6.3 L/sec = 6.4x10^{-5} m^3/sec

THE PROPERTIES OF RESIDUAL SOILS REFLECT THEIR LITHOLOGIC ORIGINS

Soil	Overlies	Permeability	Depth
Castell	gneiss	slow /moderate	moderate
Click	granite grus	rapid	deep
Katemcy	schist	slow / moderately slow	moderate
Keese	gneiss or granite	moderate / moderately rapid	shallow
Ligon	schist	slow / moderate	moderate
Lou	granite grus	moderate / rapid	moderate
Voca	granite grus	slow	very deep

Soil permeability and hence recharge are strongly influenced by lithology.

Data from the USDA NRCS

VERTICAL ZONATION

Upper / local (weathered) zone

- If present, the most productive zone

Middle zone (regional)

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

Lower (retarded flow) zone

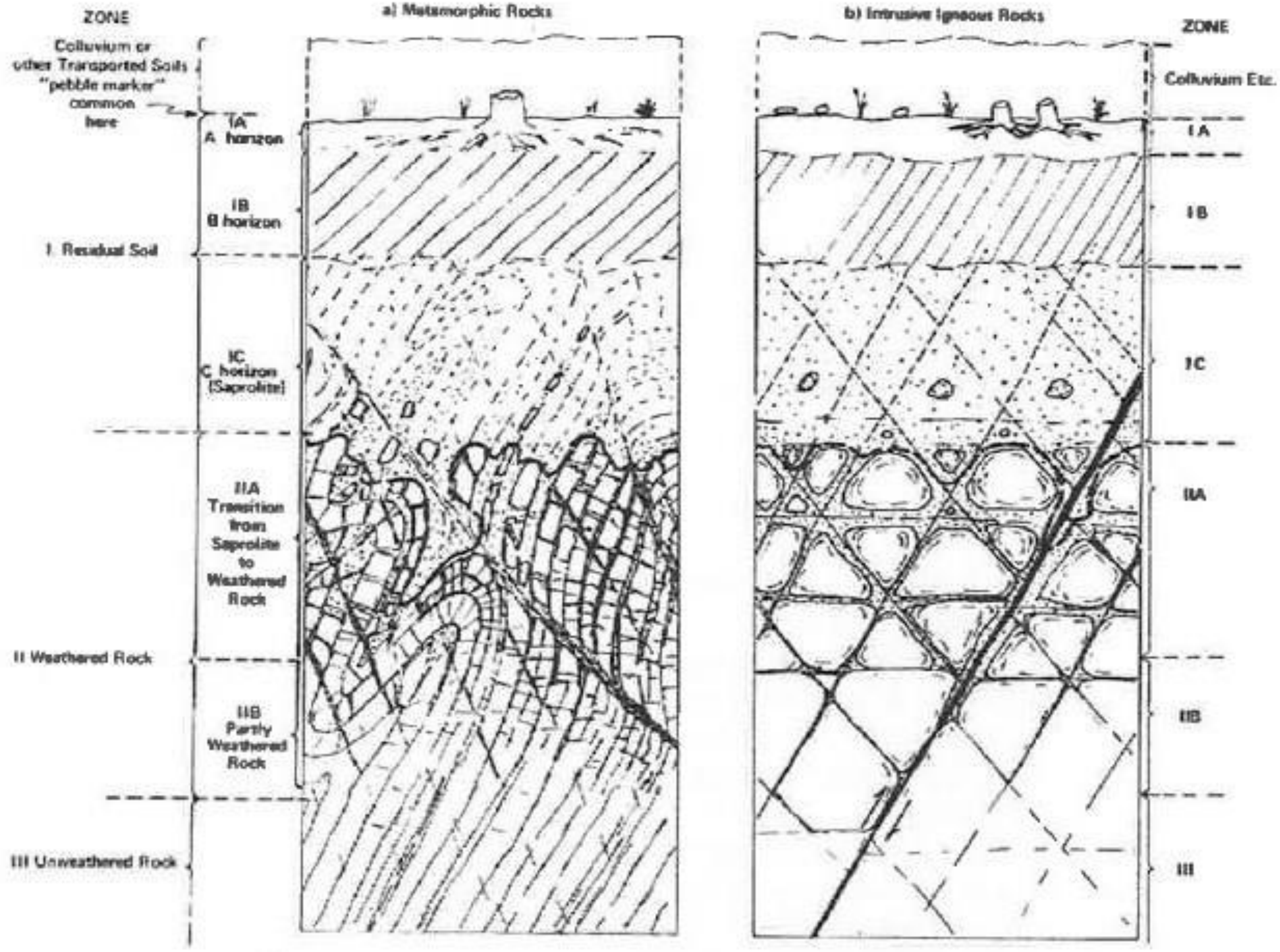
- Flow significant only in isolated fracture zones
- In rare occasions surprisingly high

Krasny & Sharp, 2007; Krasny et al. (2014)

General vertical zonation

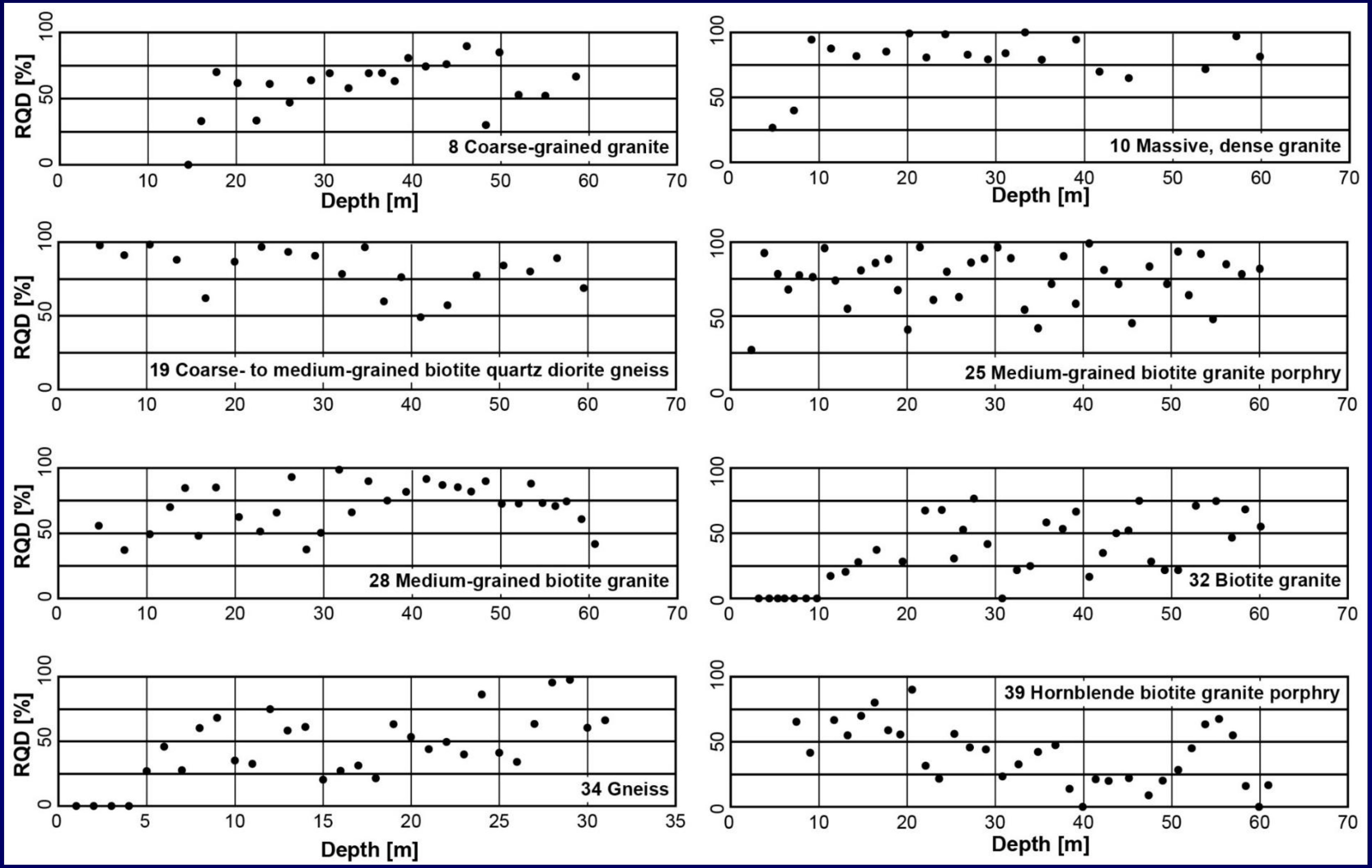
Common	Krasny & Sharp (2007)	Deere & Patton (1961)				Acworth (1987)		Lachasagne et al. (2011)		Wyns et al. (2004)
Zone	Hydrodynamical zone	Zone		RQD	k	Zone	k	Zone	k	Zone
Regolith	Upper / local (intensive & shallow)	Residual soil	Ia -O & A horizons	-	medium to high	Soil - A horizon	high	Soil not classified		
			Ib - B horizon	-	LOW	Soil - B horizon	low to medium			
			Ic - C horizon (saprolite)	0	medium	Zone a - Soil zone C	low	Clayey saprolite	low	Clayey saprolite
						Zone b	low	Sandy saprolite	low to medium	Sandy saprolite
						Zone c	low to medium			
		Weathered rock	IIa - Transition (residual soil to partly weathered rock)	variable (0 to 50%)	HIGH	Zone d - fractured and fissured rock	high to medium	Fissured layer	medium to HIGH	Upper fissured layer
Bedrock			IIb - Partly weathered rock)	generally 50 to 75 %	medium to HIGH					Lower fissured layer
	Middle / regional (intermediate)	Unweathered rock	III	> 75%	low to medium	Fresh rock	low	Fresh basement	low	Fresh basement
	Lower / retarded (slow, deep, negligible to stagnant)									
	Global (often insignificant)									

Metamorphic rocks   Plutonic rocks



Deere & Patton (1971)

Rock Quality Designation (%) vs. Depth (m)



Significant permeability can be inferred in some cores at depths

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.

However, crystalline rocks can, to some extent, retard and attenuate mass transport.

We find that along fracture walls and in fracture fills :

1) porosity is not insignificant; &

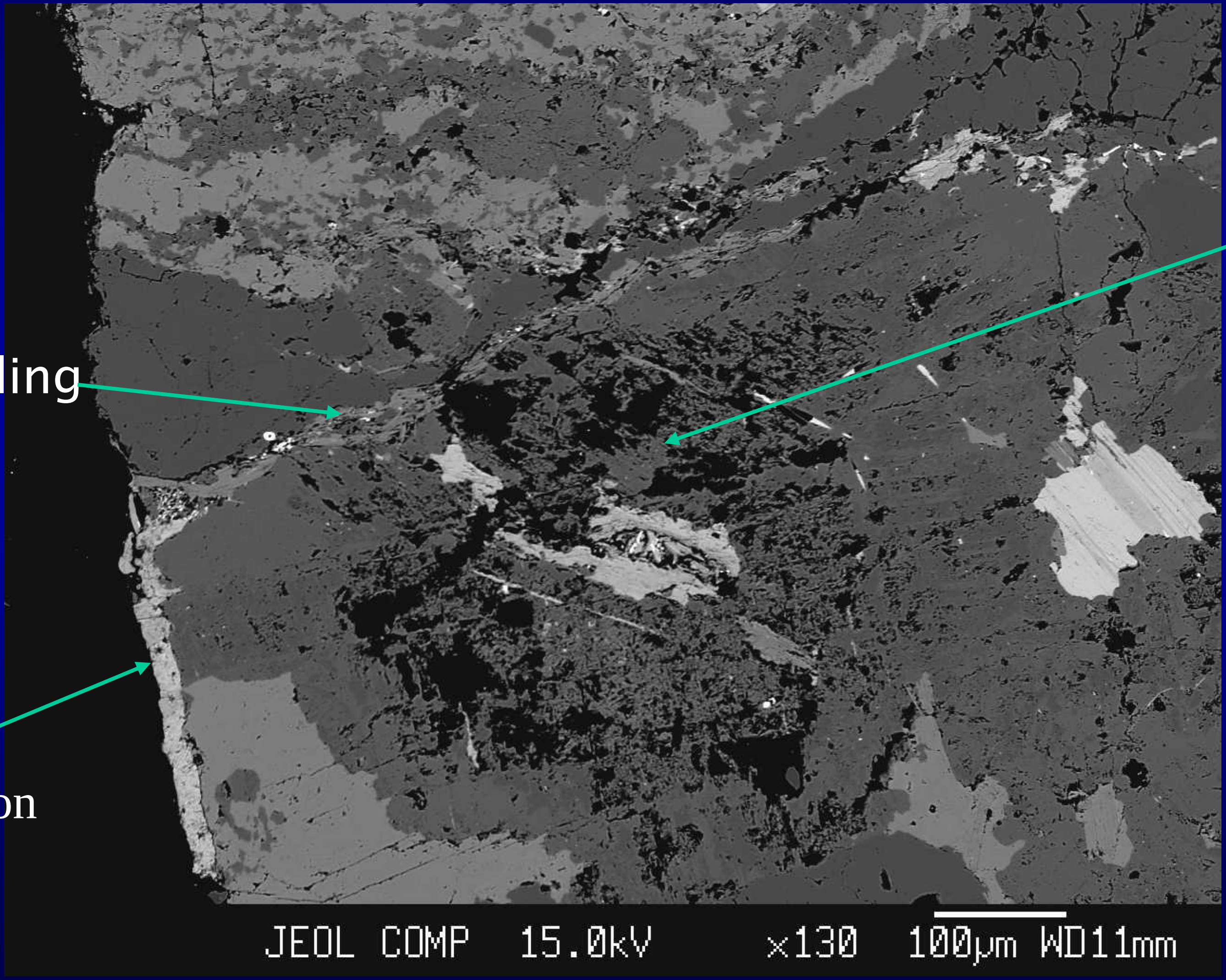
2) pores are small → large specific surface.

Sample	Porosity [%]	Median / mean pore diameter [µm]
Core #10 granite fracture fill	9.9	0.2884 / 0.1563
Fredericksburg Town Mountain Granite skin	6.1	8.569 / -
Core# 6 gneiss fracture fill	2.0	7.392 / -
Core #34 gneiss fracture fill	15.5	0.204 / 0.0861
Australian Calca (green) Granite skin	5.6	.0339 / 0.1014

Hg-injection porosimetry courtesy of Glen Baum (Univ. Texas)

Skin development
(Elberton granite, Georgia, USA)

Clay Infilling



Core Softening

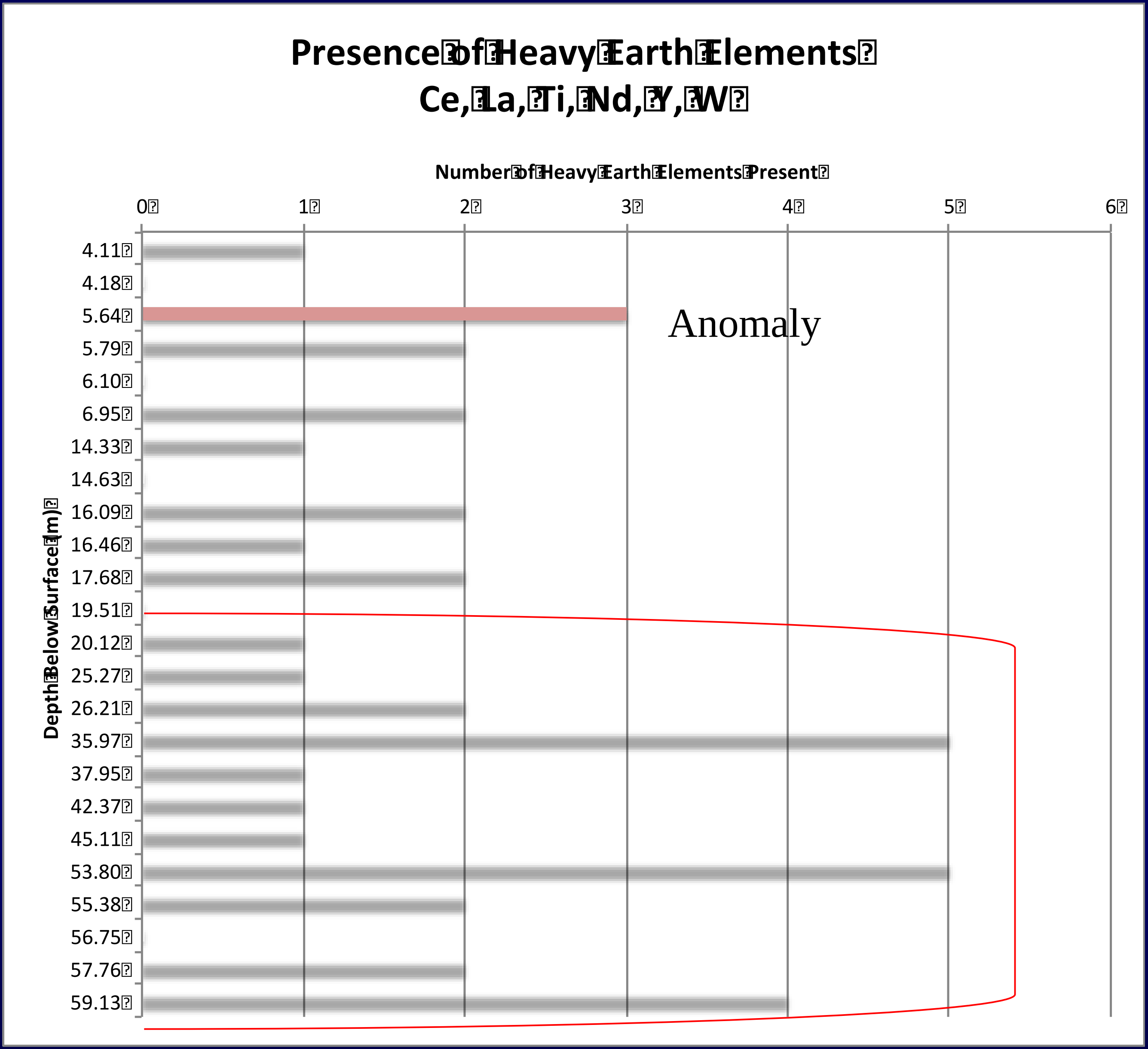
(High Porosity)

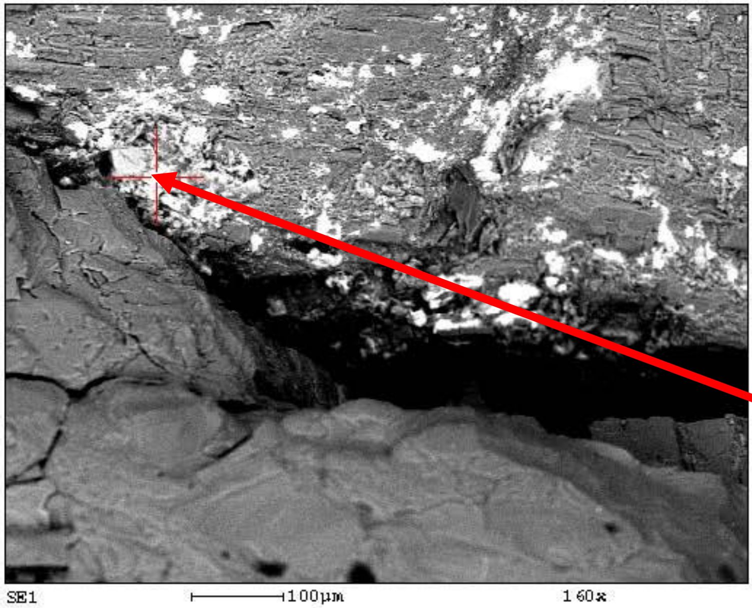
Chlorite Precipitation

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

Thickness

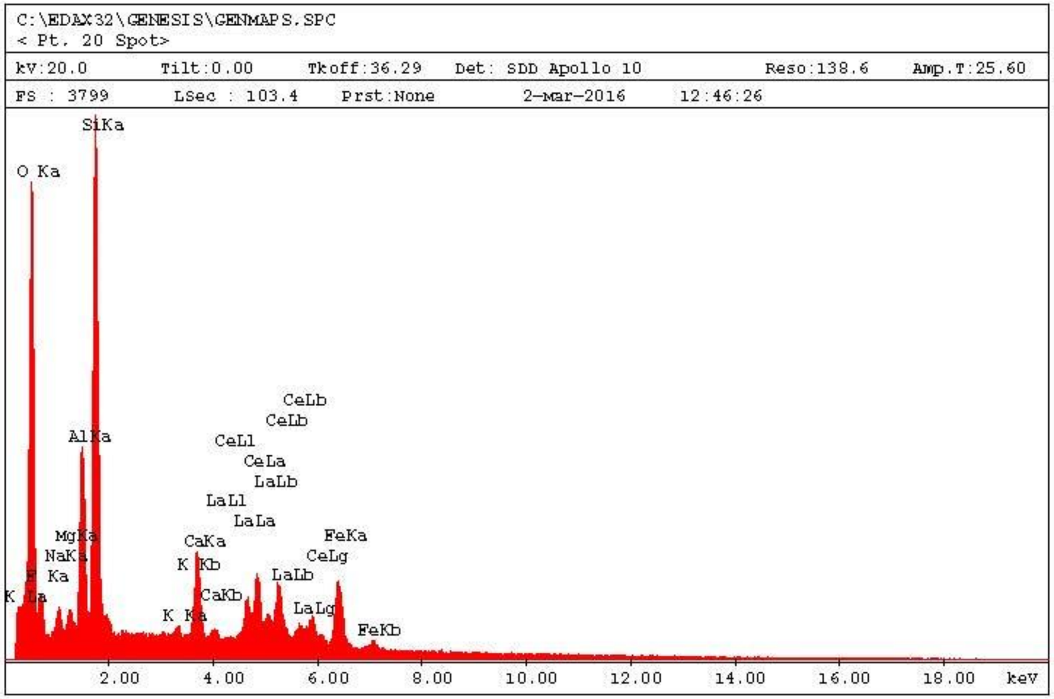
Presence of elements in skin coatings

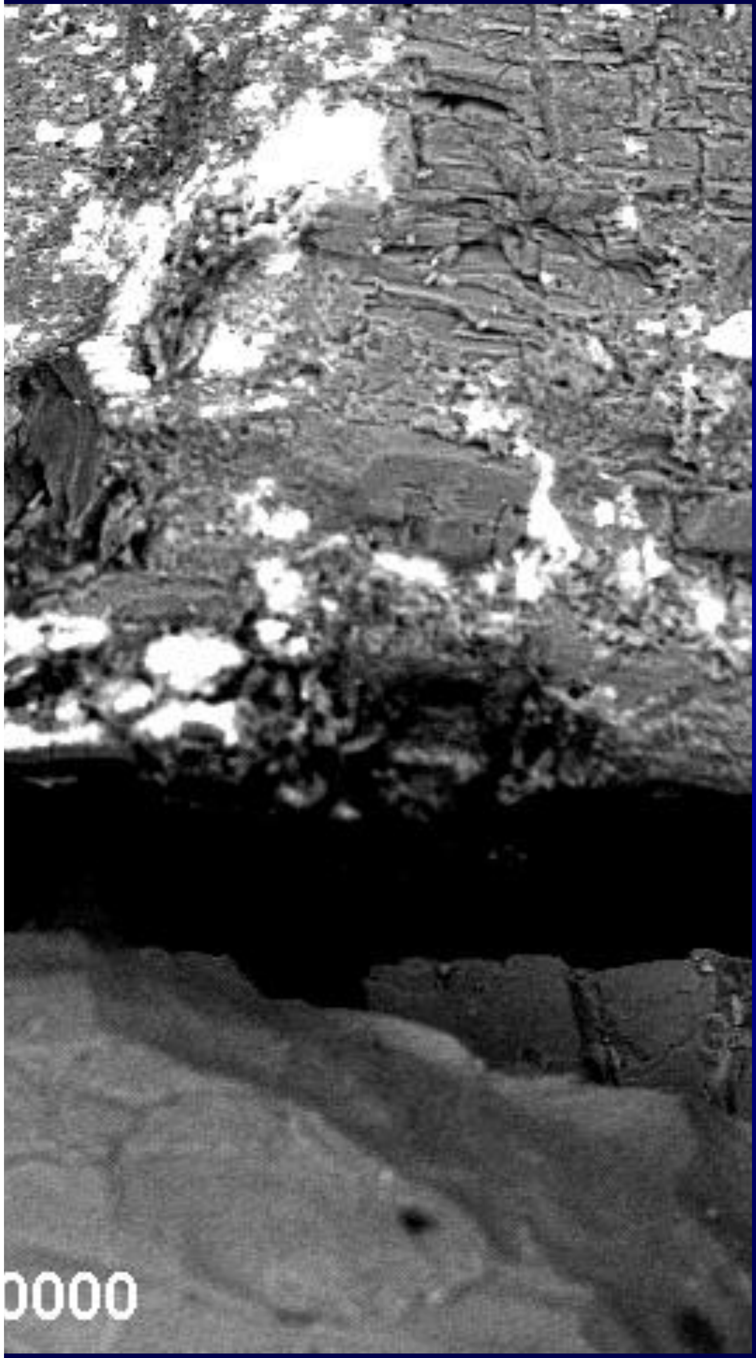


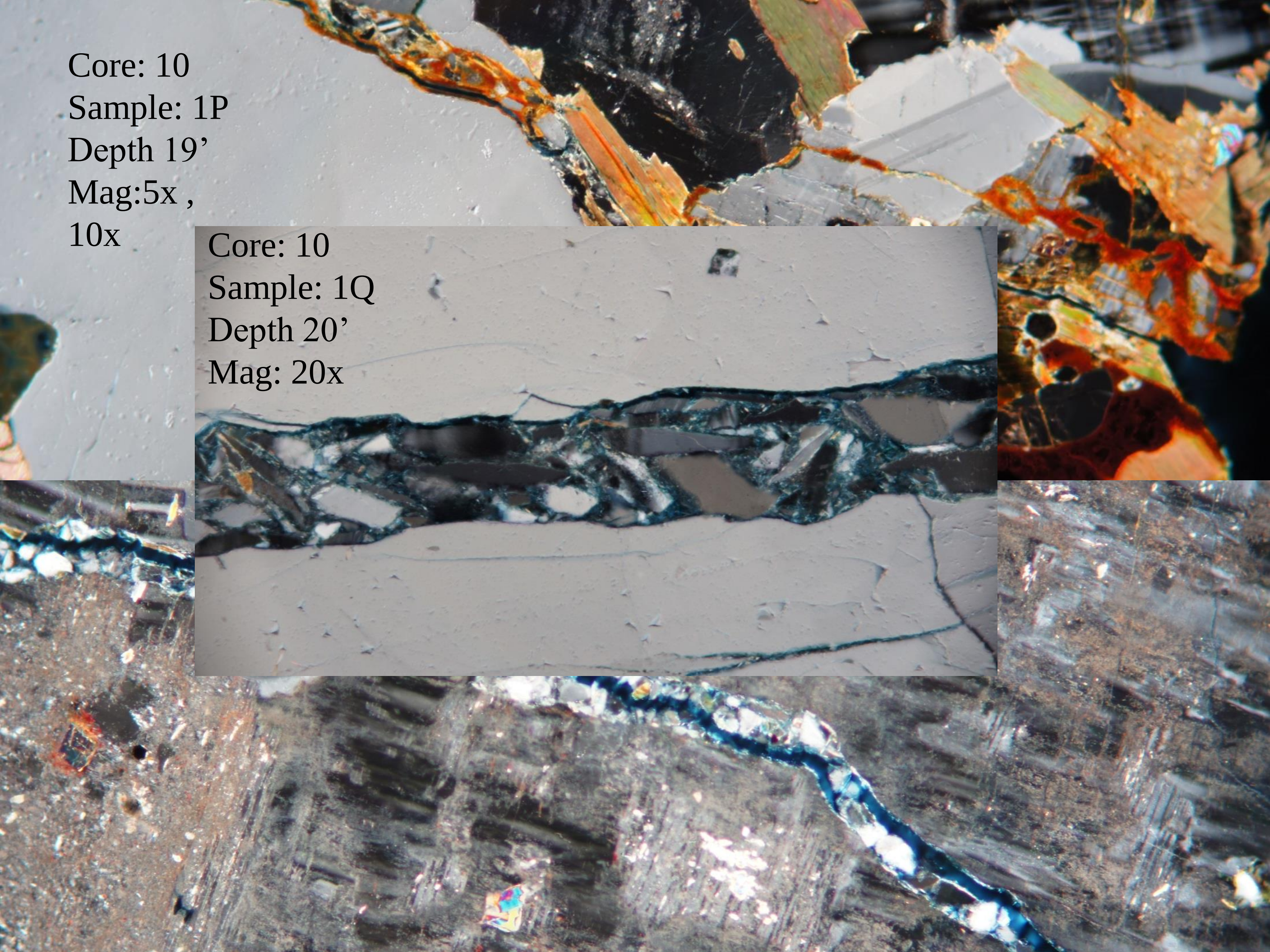


EDS Quantitative Results

Element	Wt%	At%
OK	29.39	50.89
FK	3.88	5.66
NaK	1.49	1.79
MgK	0.92	1.05
AlK	7.79	8.00
SiK	21.13	20.84
KK	0.48	0.34
CaK	4.05	2.80
LaL	8.37	1.67
CeL	14.06	2.78
FeK	8.45	4.19

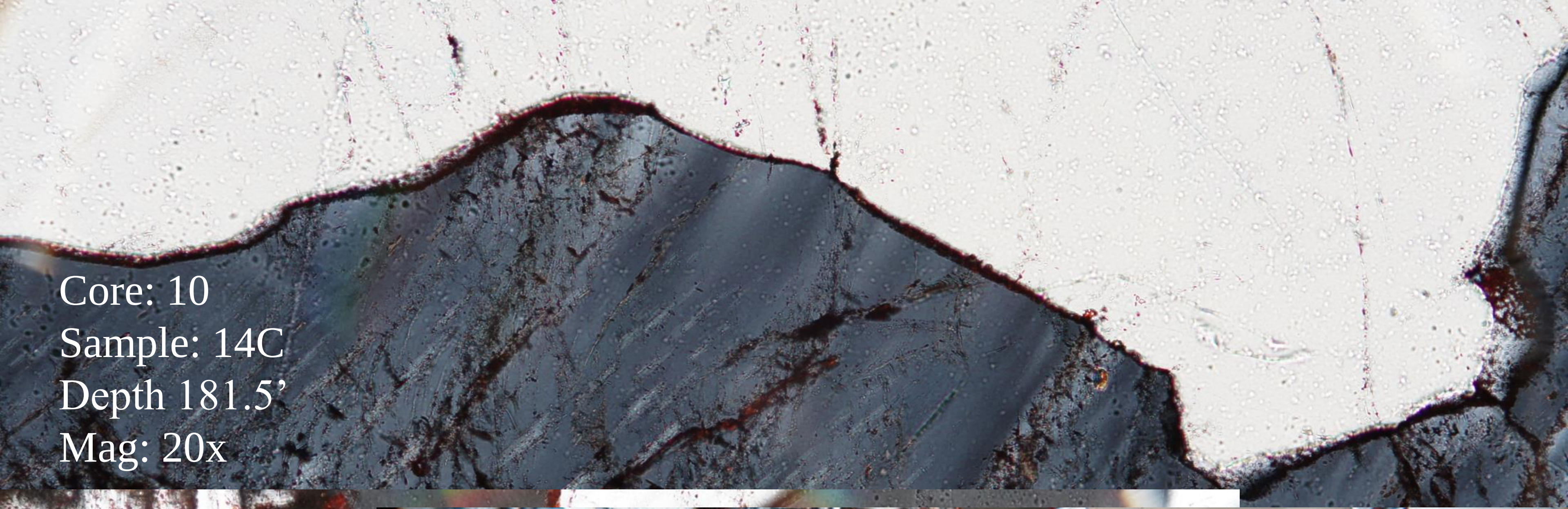




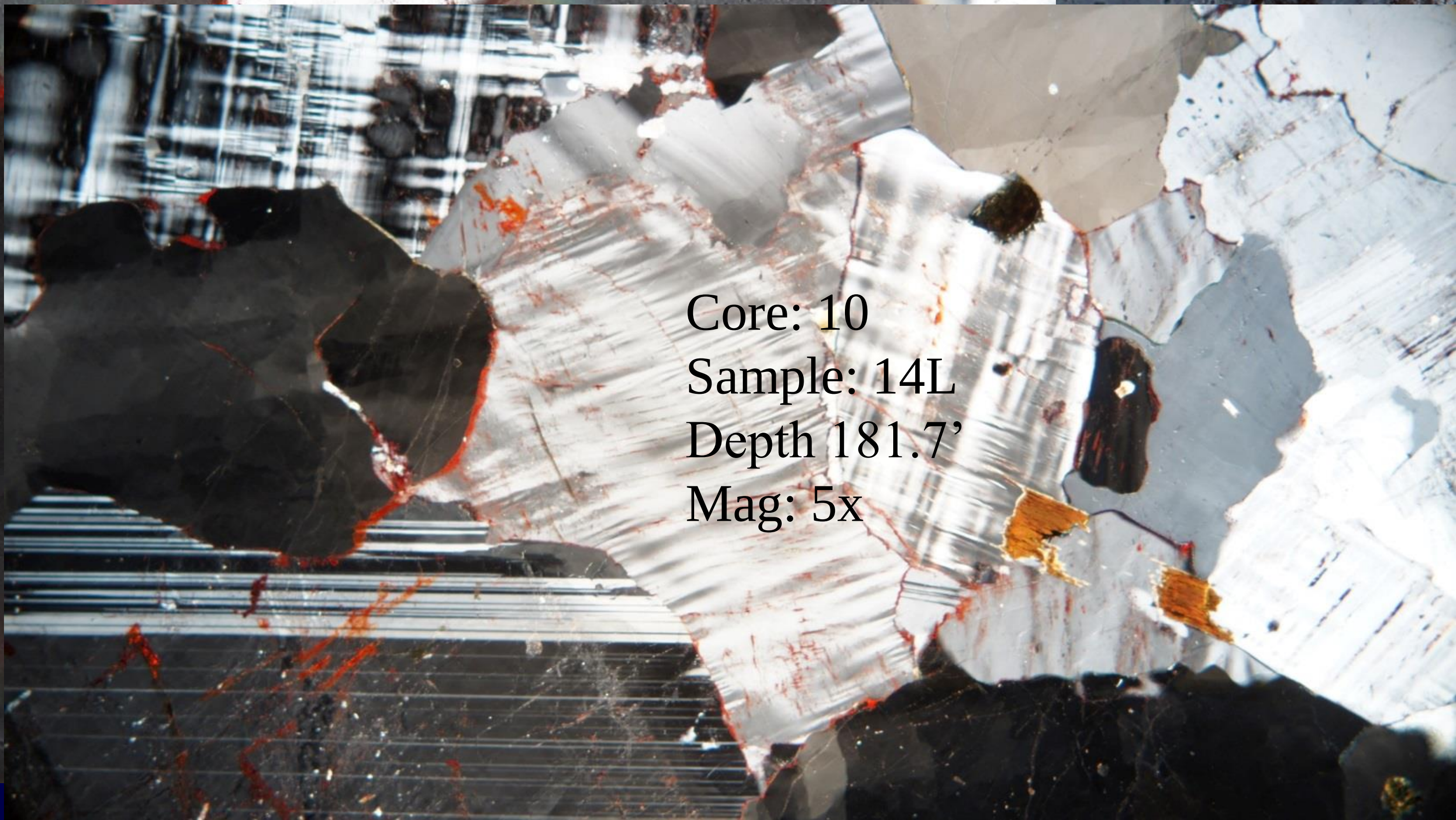


Core: 10
Sample: 1P
Depth 19’
Mag:5x ,
10x

Core: 10
Sample: 1Q
Depth 20’
Mag: 20x


Core: 10
Sample: 14C
Depth 181.5’
Mag: 20x


Core: 10
Sample: 14L
Depth 181.7’
Mag: 10x


Core: 10
Sample: 14L
Depth 181.7’
Mag: 5x

Fracture fills and skins

- These are ubiquitous.
- Near the surface they are thicker and more ferruginous. Open Fractures are more abundant.
- With depth they are thinner and appear more reduced. Filled fractures are more abundant
- Trace elements (e.g., Ce, Ti, and La are more prominent.
- Porosity is not insignificant.
- Specific surface is significant.
- They can to some extent retard and attenuate mass (including contaminant) transport.

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.
- Identifying permeable fracture systems at depths.

CONCLUSIONS

- Permeabilities generally decrease with depth.
- Recently more deeper wells are being drilled.
- Thick weathered zones (grus) can be highly productive.
- The 100 m rule of thumb generally holds, but fracture zones at depths can be productive.
- *A priori* prediction of these deeper fractures is difficult.
- Weathering along fractures increases porosity and specific surface (& will affect solute transport).
- We observe strong fissuring parallel to the ground surface in the weathered zone.

Acknowledgements

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