MACROPORES IN THE PALEOZOIC AQUIFER SYSTEM OF SOUTHEASTERN MINNESOTA: WHAT WE KNOW AND WHAT WE ~~DON'T KNOW~~ WILL SOON FIGURE OUT

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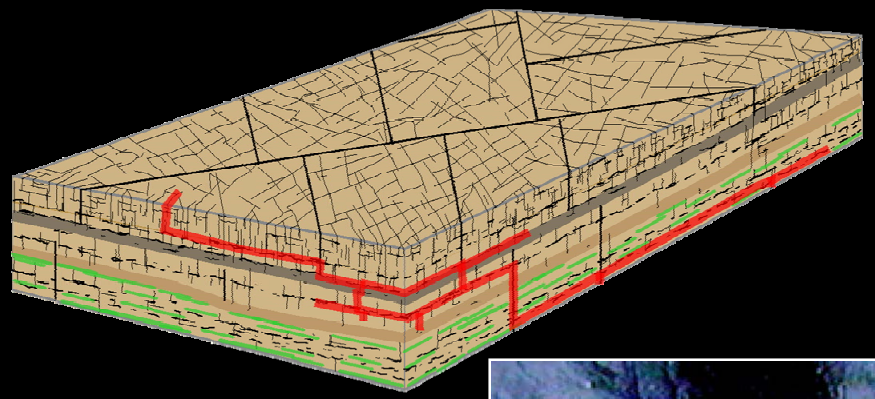
Minnesota Geological Survey

FUNDING MOSTLY THROUGH LCCMR, MET COUNCIL, MDH, MPCA AND GENERAL FUNDS TO THE MGS

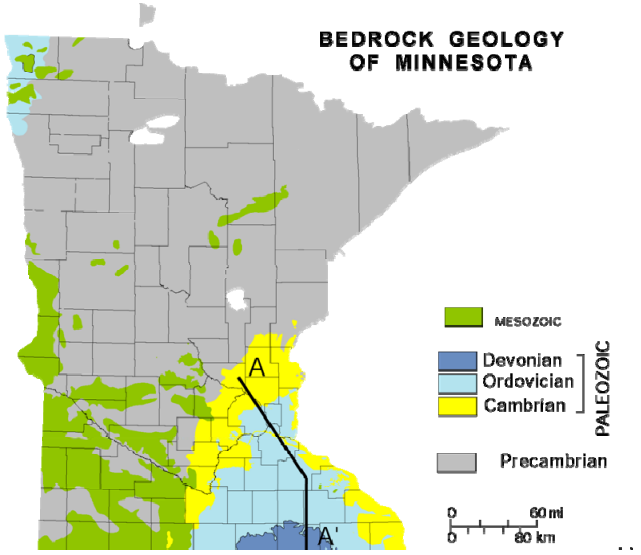
OBJECTIVES OF TALK ARE TO SHOW THAT:

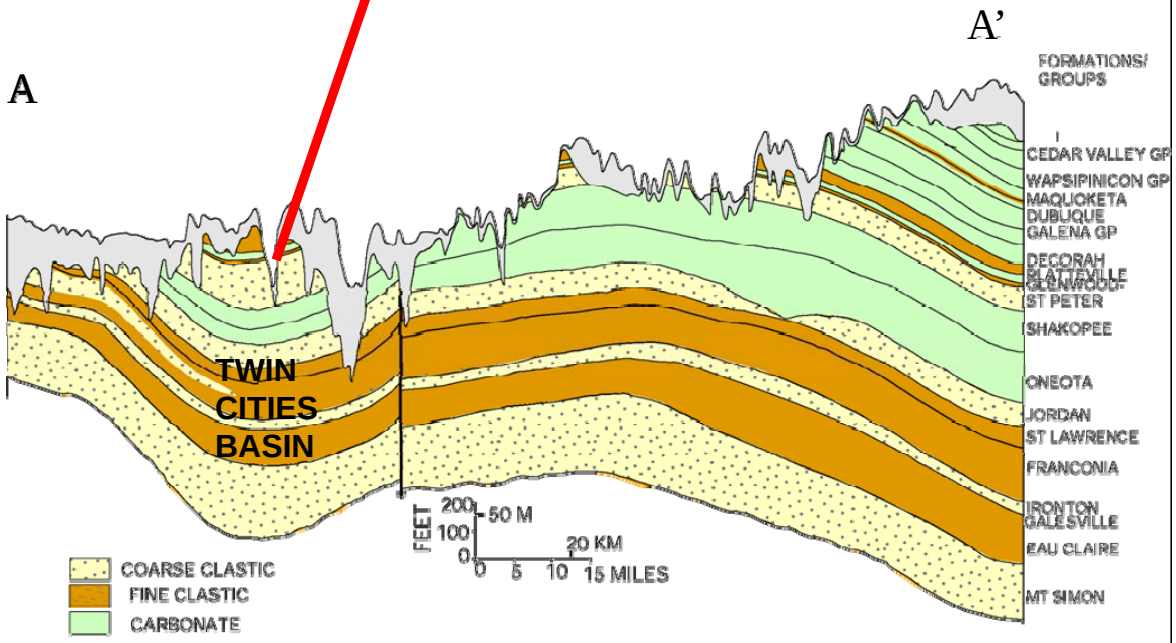
- MACROPORES IN ALL BEDROCK
- MACROPORES HYDROLOGICALLY IMPORTANT
-WE CAN "MAP" (PREDICT) MACROPORES



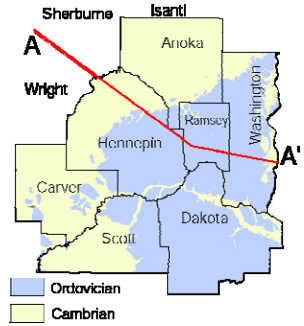
PALEOZOIC BEDROCK

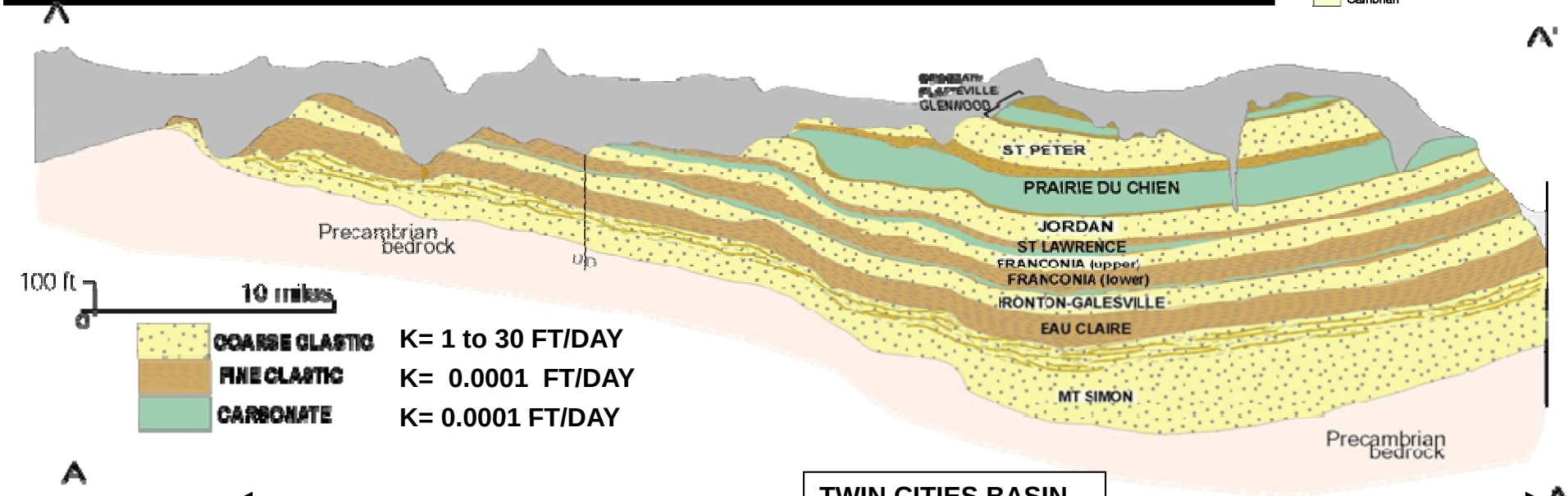
Deposited mostly in marine setting
505 to 350 ma
Thin layers of sandstone, shale, carbonate
The most heavily used aquifers in Minnesota

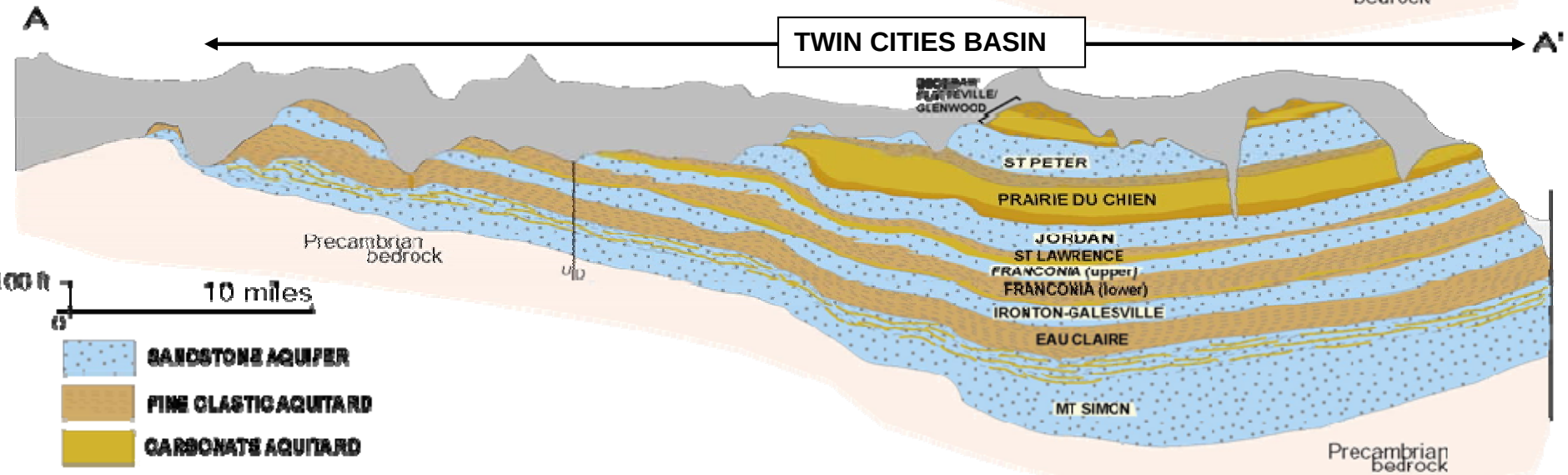




HYDROGEOLOGIC PROPERTIES:
MATRIX (INTERGRANULAR) PROPERTIES





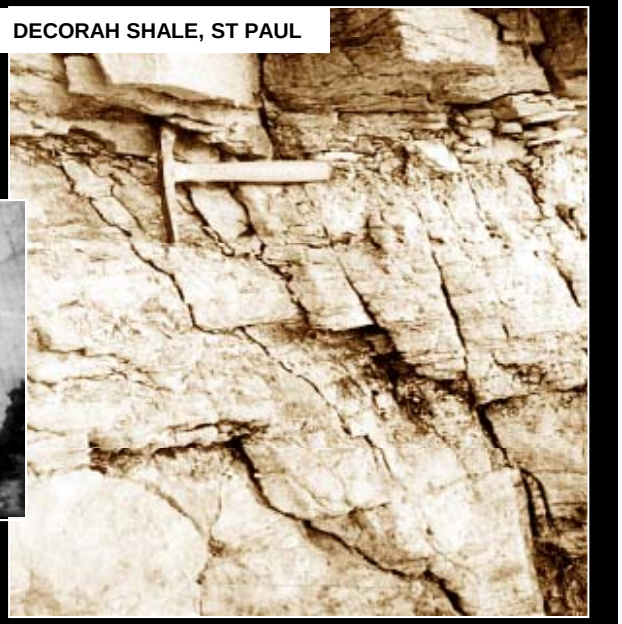


OVERVIEW OF MACRO PORES

ST PETER-PLATTVILLE, ST PAUL

"VERTICAL" FRACTURES

DECORAH SHALE, ST PAUL



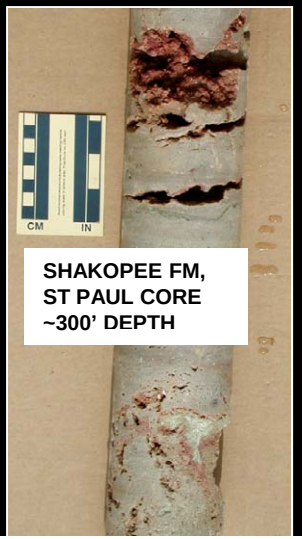
PALEOZOIC, EASTERN WI

ST LAWRENCE FM, RED WING

BEDDING PLANE " FRACTURES" (BPFS)

FRANCONIA FM, STILLWATER

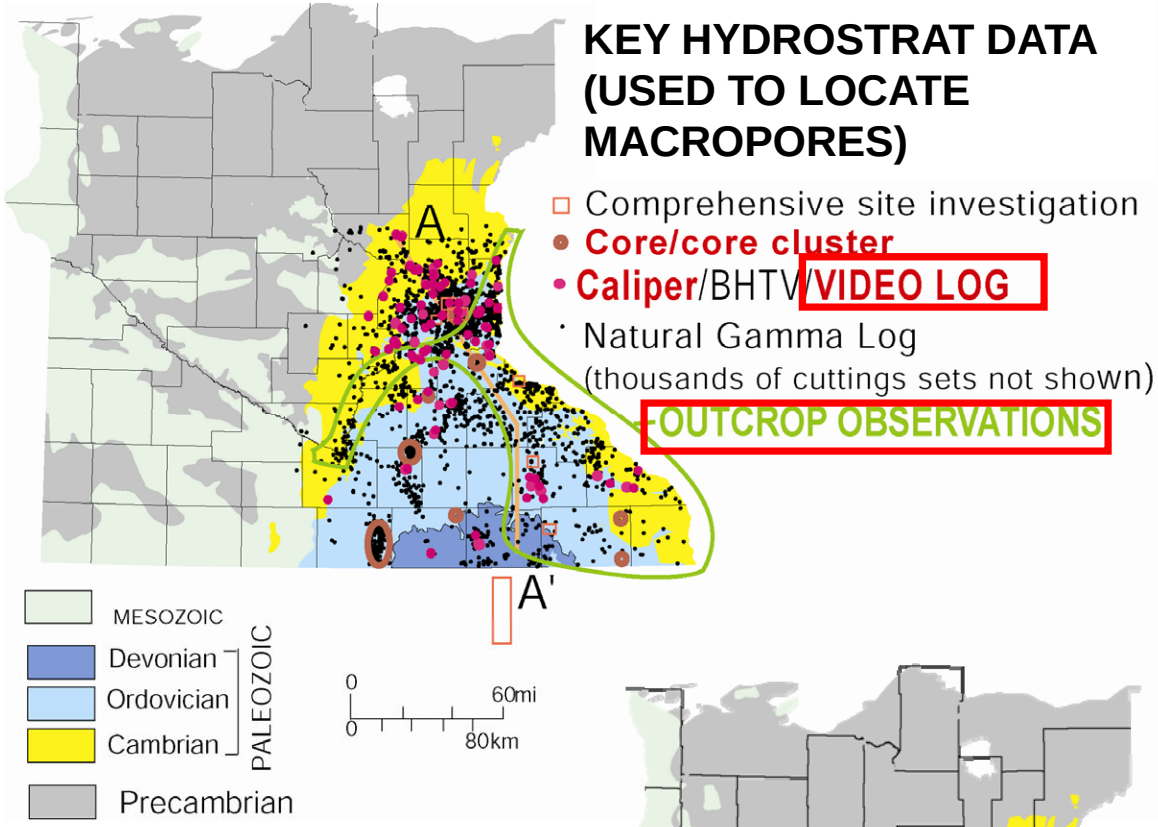
FRANCONIA FORMATION, STILLWATER BOREHOLE, ~313' DEPTH



SHAKOPEE FM, ST PAUL CORE ~300' DEPTH

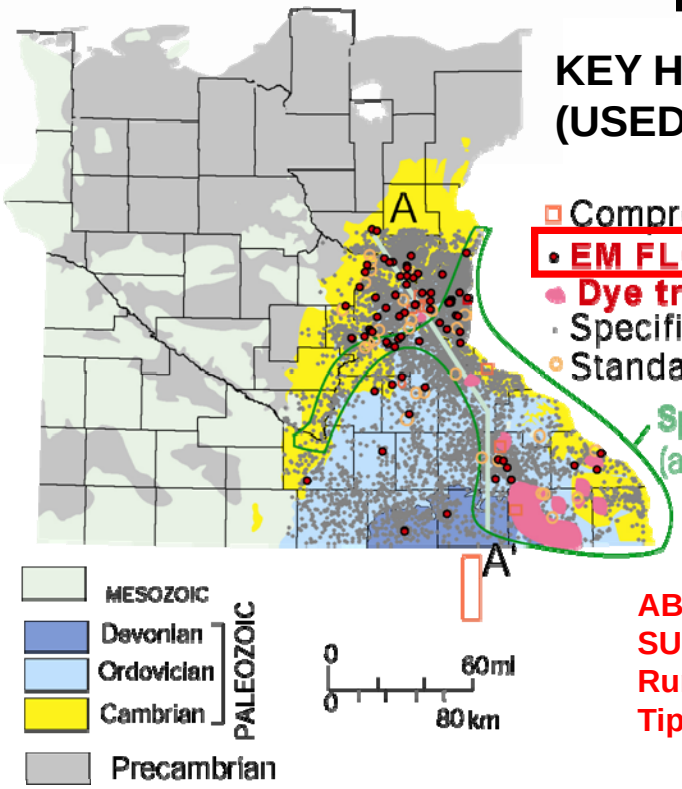
THE DATA

KEY HYDROSTRAT DATA (USED TO LOCATE MACROPORES)



- Comprehensive site investigation
- Core/core cluster
- Caliper/BHTV/VIDEO LOG
- Natural Gamma Log (thousands of cuttings sets not shown)
- OUTCROP OBSERVATIONS

KEY HYDRAURLIC DATA (USED TO MEASURE FLOW)



- Comprehensive site investigation
- EM FLOWMETER LOG (with temp, cond., video logs)
- Dye trace
- Specific capacity/hydraulic conductivity
- Standard pump tests
- Spring/Sinkhole data (approx. = area of outcrop)

ABOUT 100 FLOW LOGS, MOST SUMMARIZED IN:
Runkel and others (2003, 2006a,b, 2008)
Tipping and others (2006)

PART ONE: BEDDING PLANE FRACTURES/VUGS (BPFS)

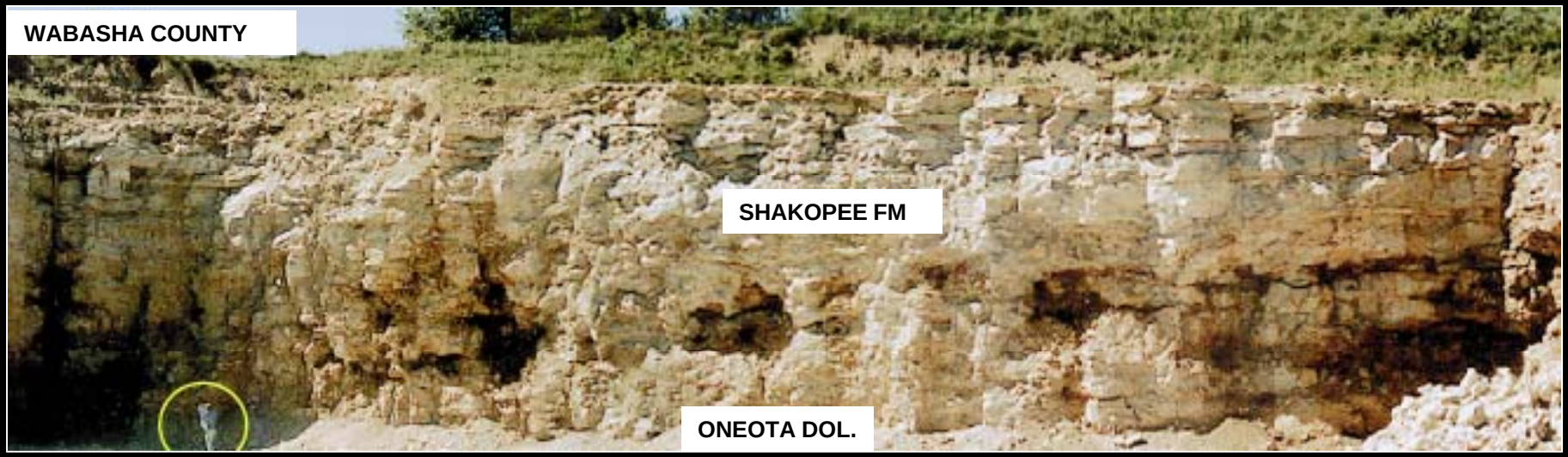
OUTCROP EXAMPLES

PLATTEVILLE FM, HENNEPIN CO

ST LAWRENCE FM, ST CROIX RIVER BLUFF

FRANCONIA FM, ST CROIX RIVER BLUFF

JORDAN Ss, ST CROIX RIVER BLUFF



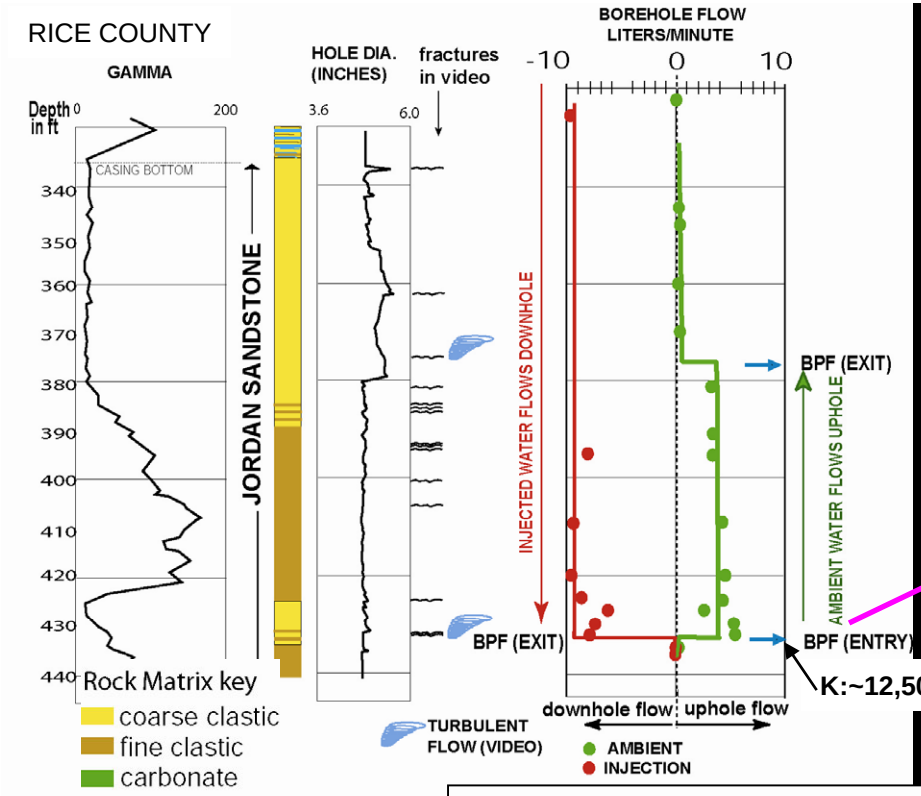
WABASHA COUNTY

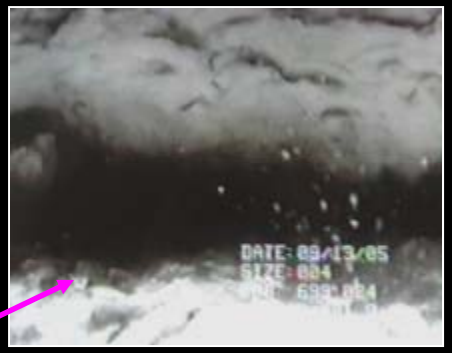
SHAKOPEE FM

ONEOTA DOL.

BPF FLOW IN FRIABLE COARSE CLASTIC UNITS

RICE COUNTY

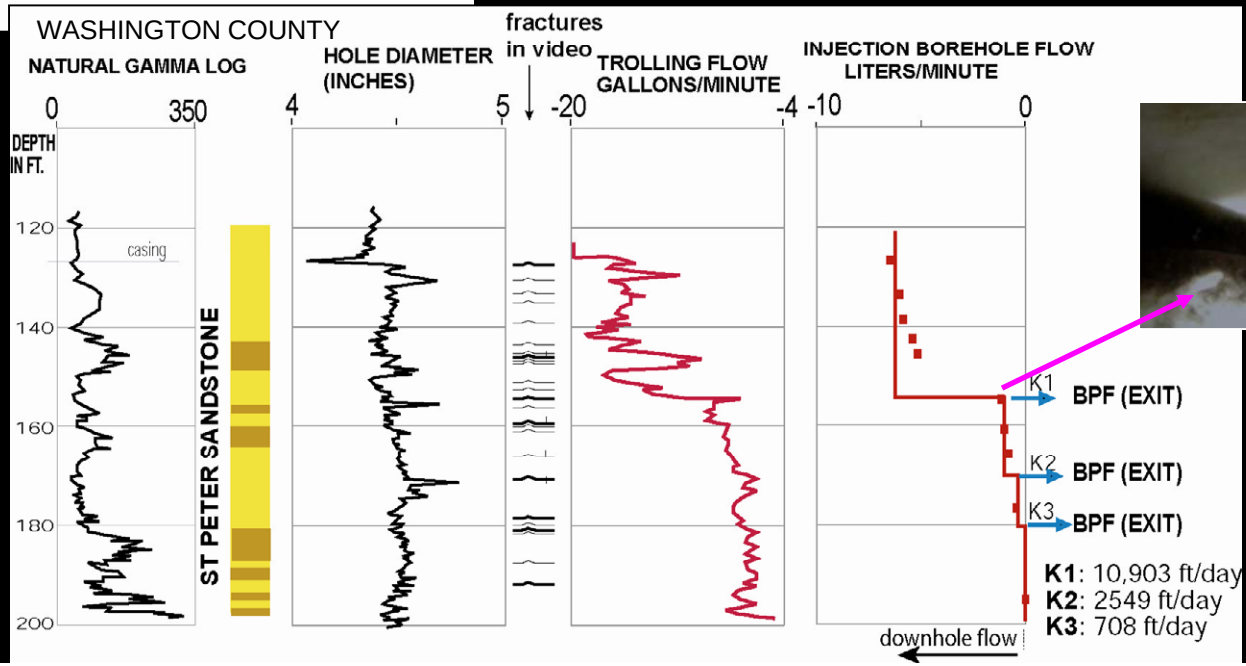




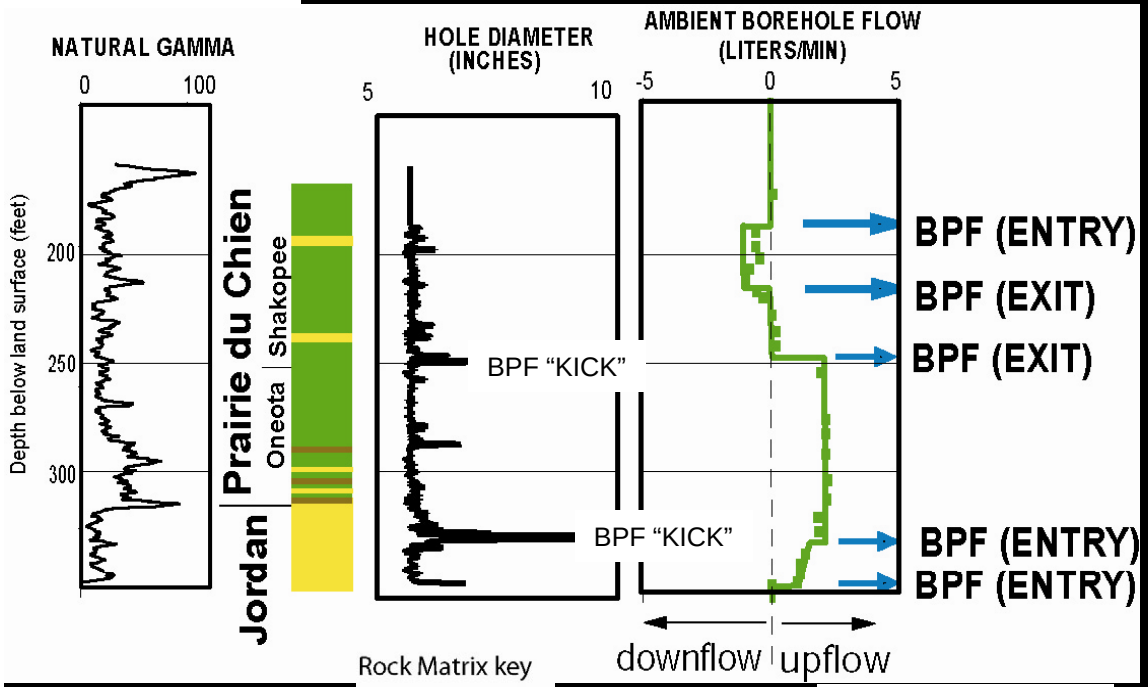
K:~12,500 ft/day

TYPICAL LOGS
(>90%) FRACTURE FLOW
K 100'S TO 1000'S ft/day

WASHINGTON COUNTY



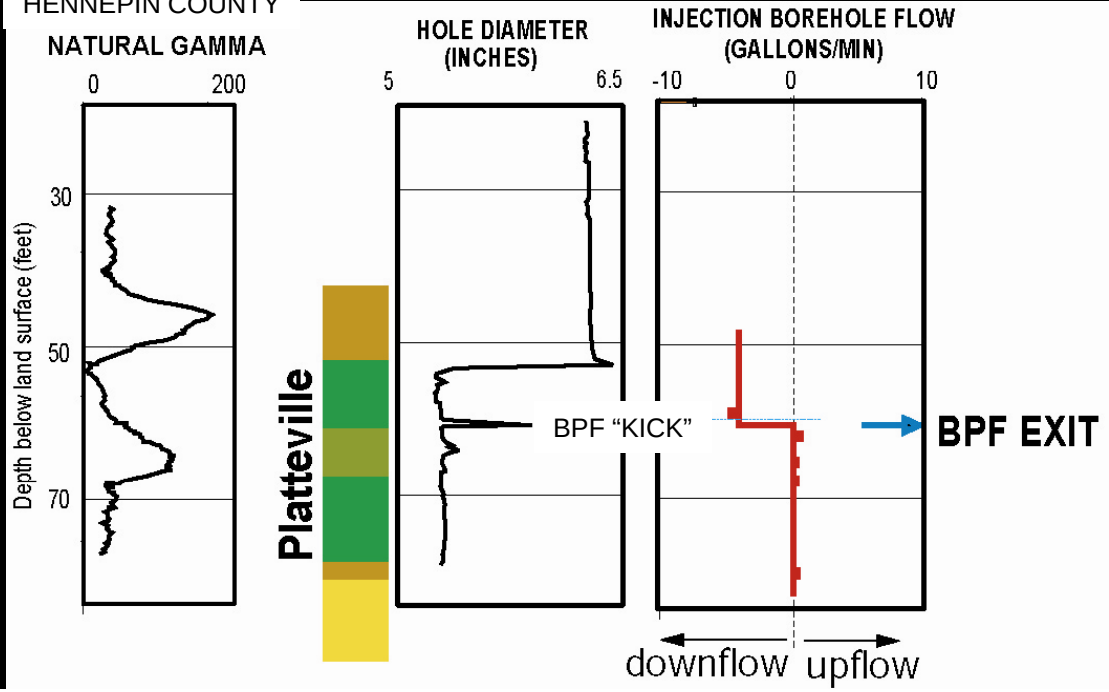
HENNEPIN COUNTY



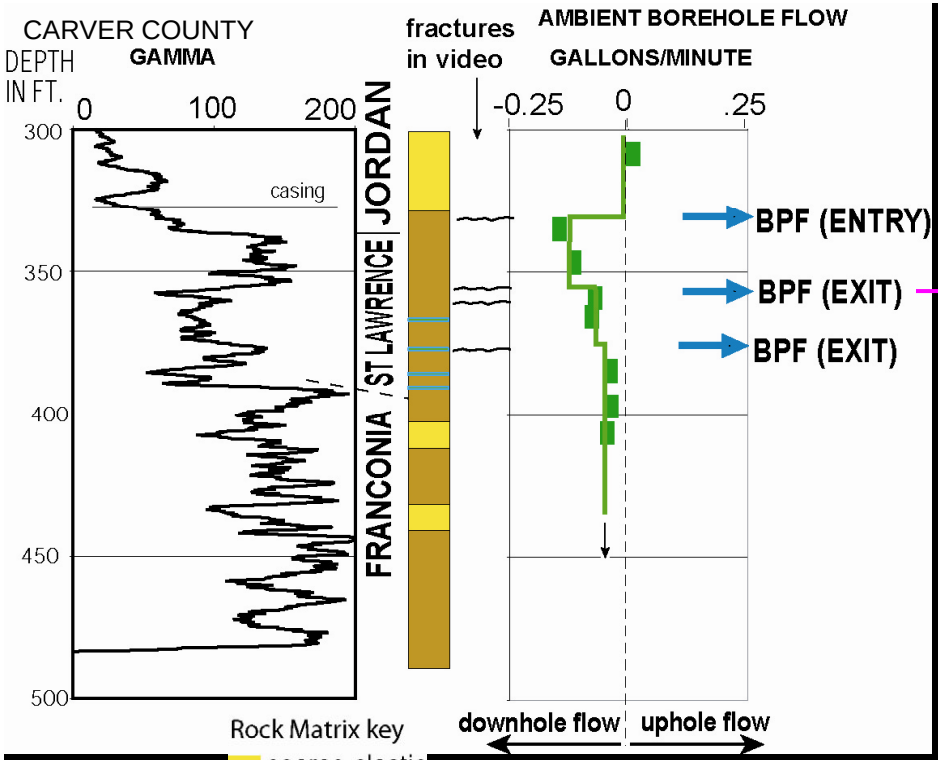
BPF FLOW IN CARBONATE UNITS

TYPICAL LOGS
(>90%) FRACTURE FLOW
K 100'S TO 1000'S ft/day

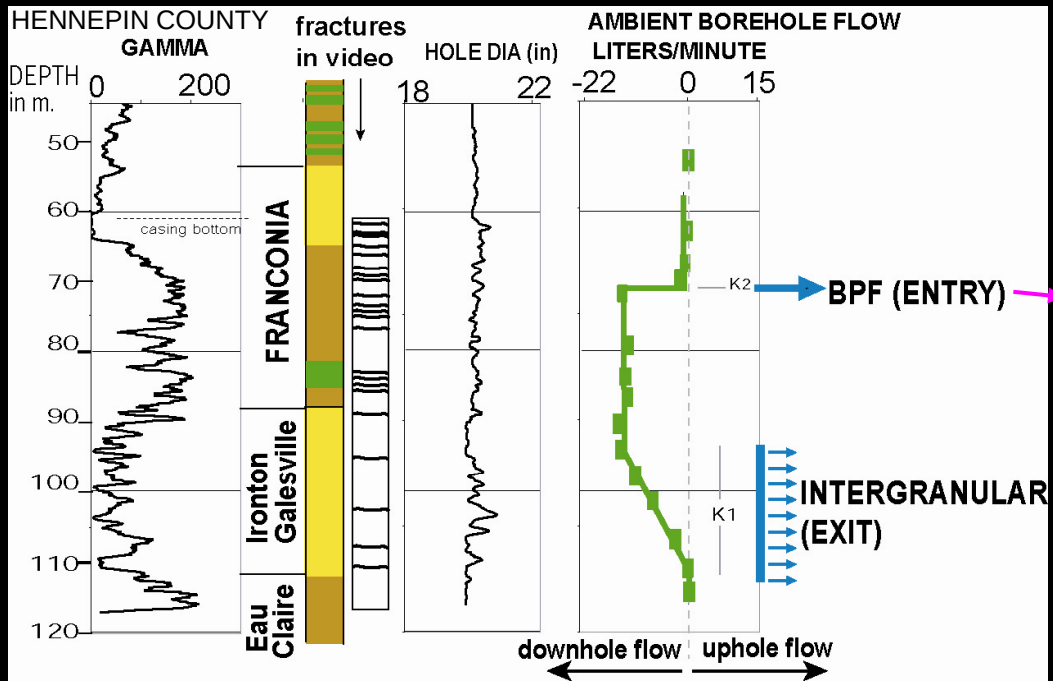
HENNEPIN COUNTY

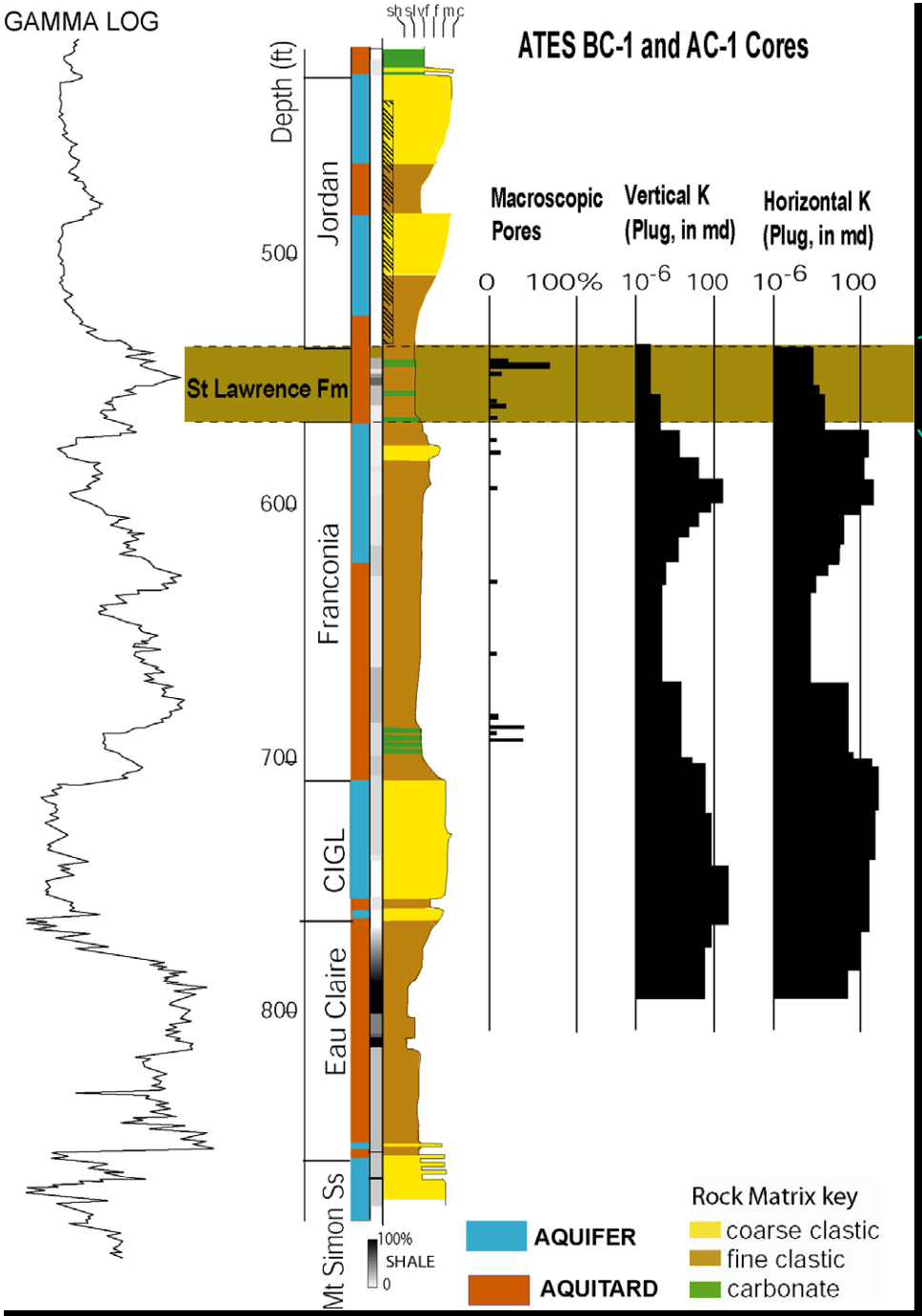


BPF FLOW IN FINE CLASTIC UNITS



TYPICAL LOGS
(>90%) FRACTURE FLOW
K 10'S TO 1000'S ft/day





IMPLICATIONS OF BPFS IN AQUITARDS

Example: St Lawrence Fm

-FINE CLASTIC, MINOR CARBONATE, WITH MATRIX K 10-4 FT/DAY OR LESS

-BULK VERTICAL K MEASURED AT < 10-4 FT/DAY

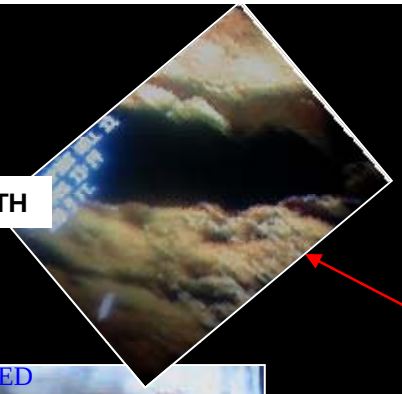
-HEADS ABOVE AND BELOW DIFFER

ST LAWRENCE AQUITARD BPFS PRESENT REGIONALLY

BPFS in St Lawrence Aquitard are present regionally: ambient flow through at least one BPF measured in 14 of 17 tested boreholes

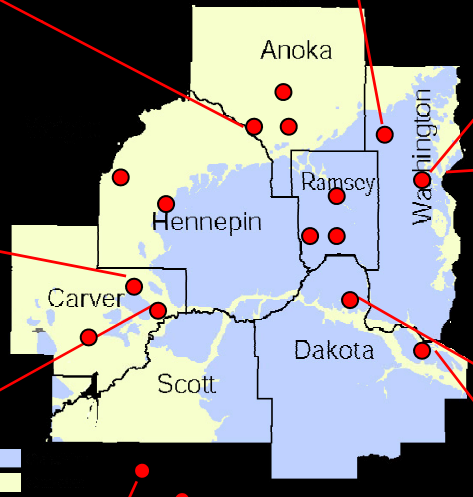
297' DEPTH

260' DEPTH



191' DEPTH

415' DEPTH



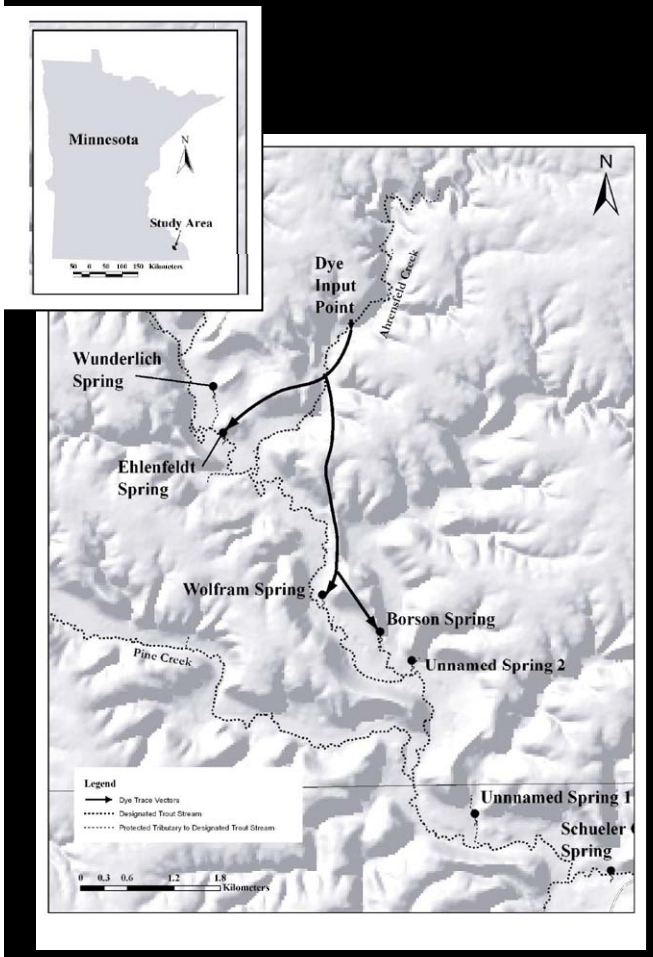
355' DEPTH

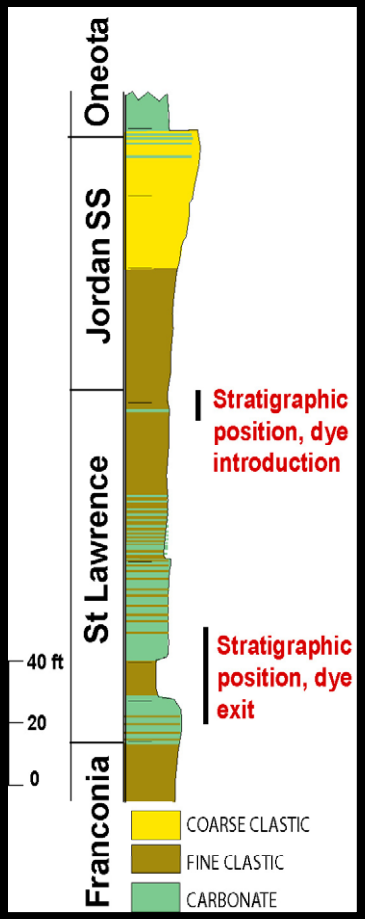
339' DEPTH

218' DEPTH

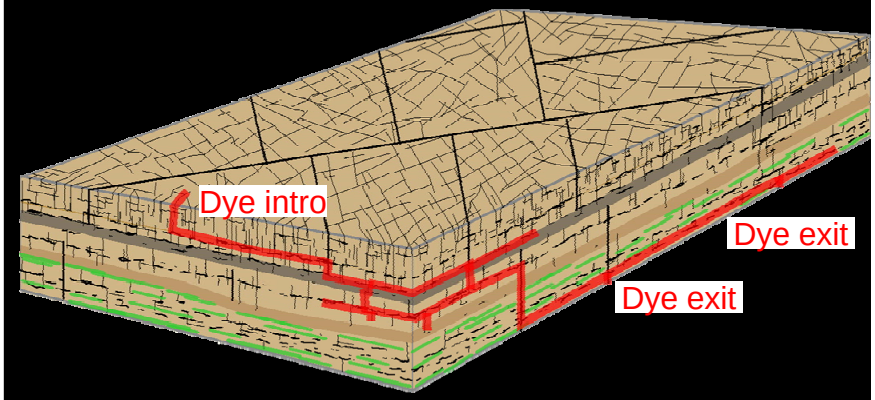
273' DEPTH

ST LAWRENCE AQUITARD: RECENT DYE TRACE (Jeff Green, MNDNR; Green and others, 2008))

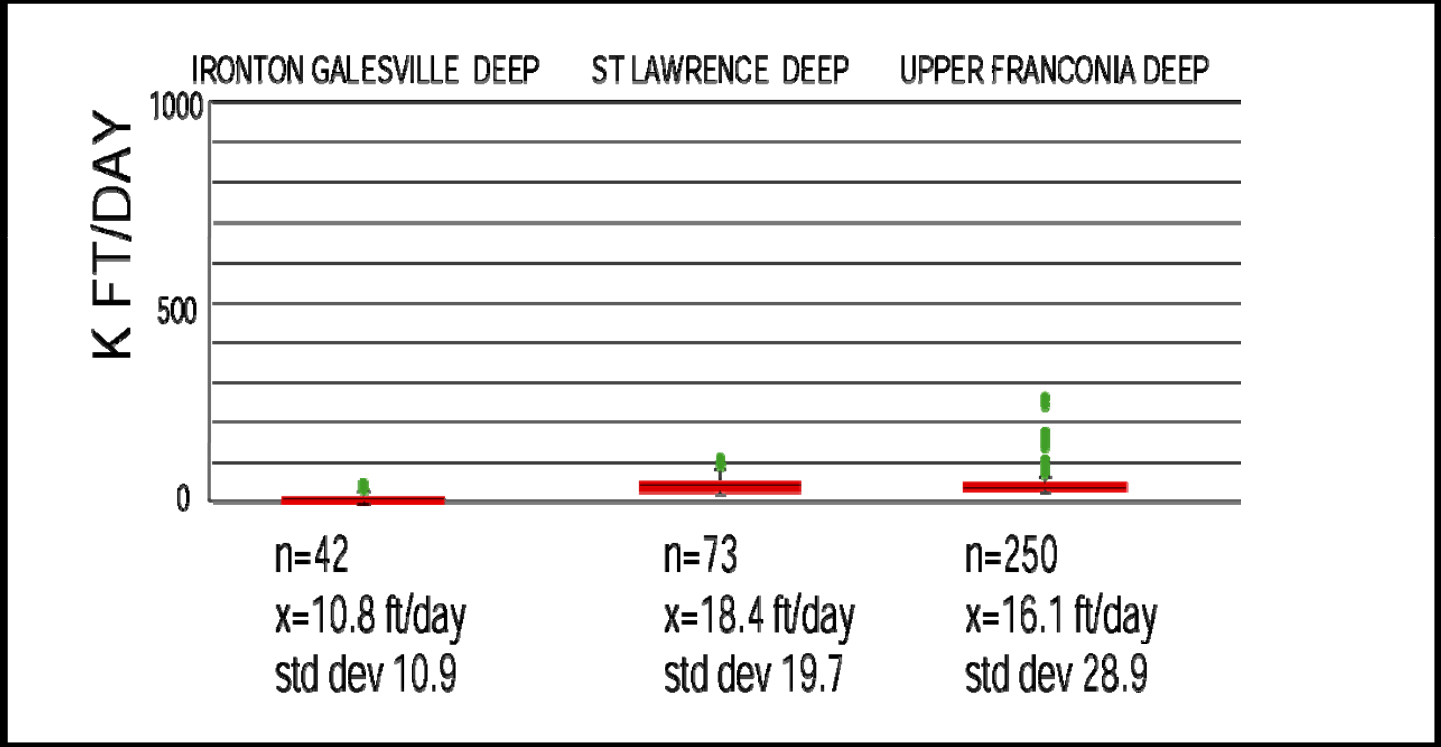




-Horizontal flow speed, 100's meters/day
-Vertical flow speed, meters/day



ST LAWRENCE FORMATION YIELDS COMPARABLE TO ACKNOWLEDGED AQUIFERS



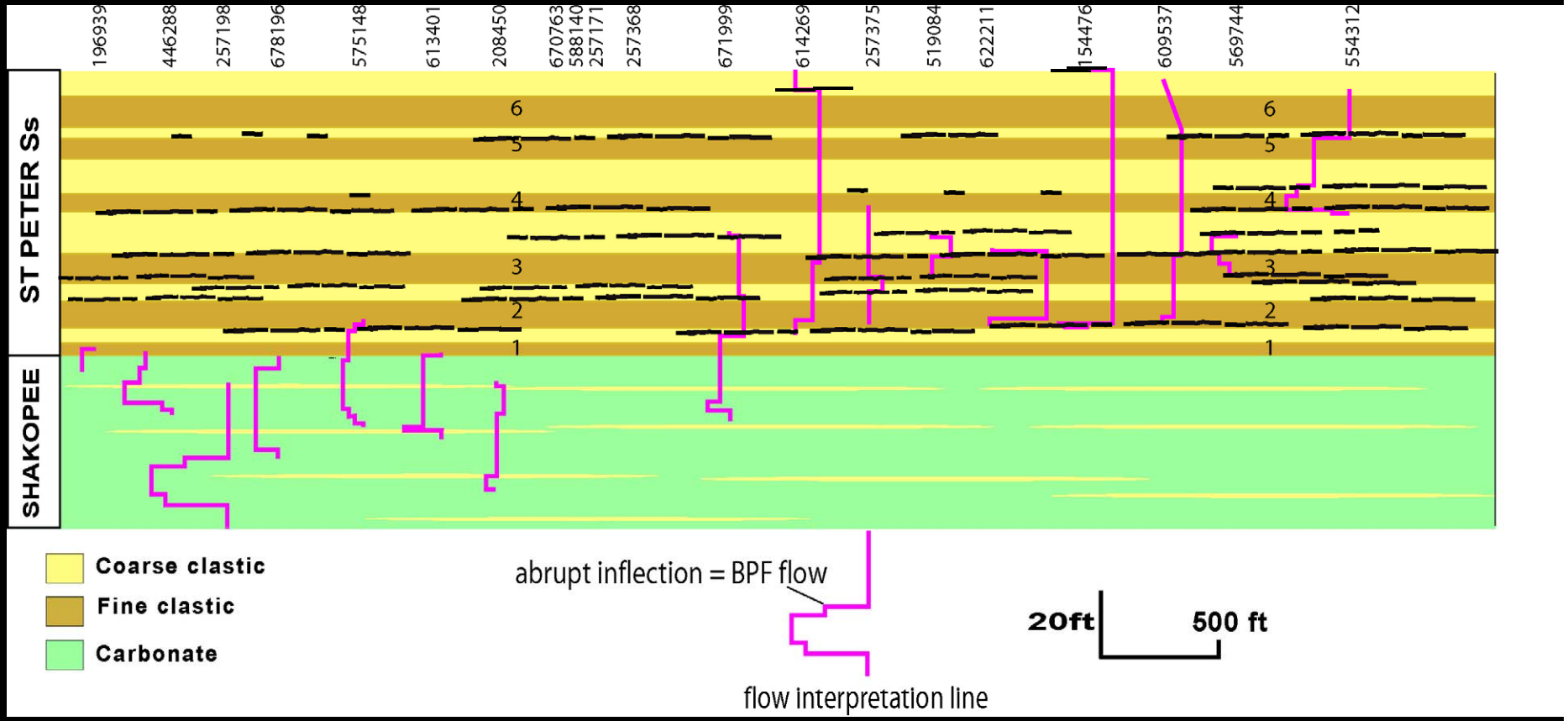
IS THE ST LAWRENCE FORMATION AN AQUIFER?

IS THE ST LAWRENCE FORMATION AN AQUITARD?

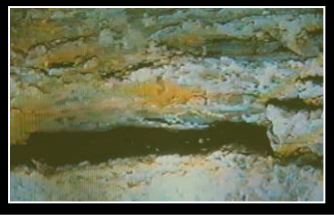
IS THE ST LAWRENCE FORMATION AN AQUITARDIFER?

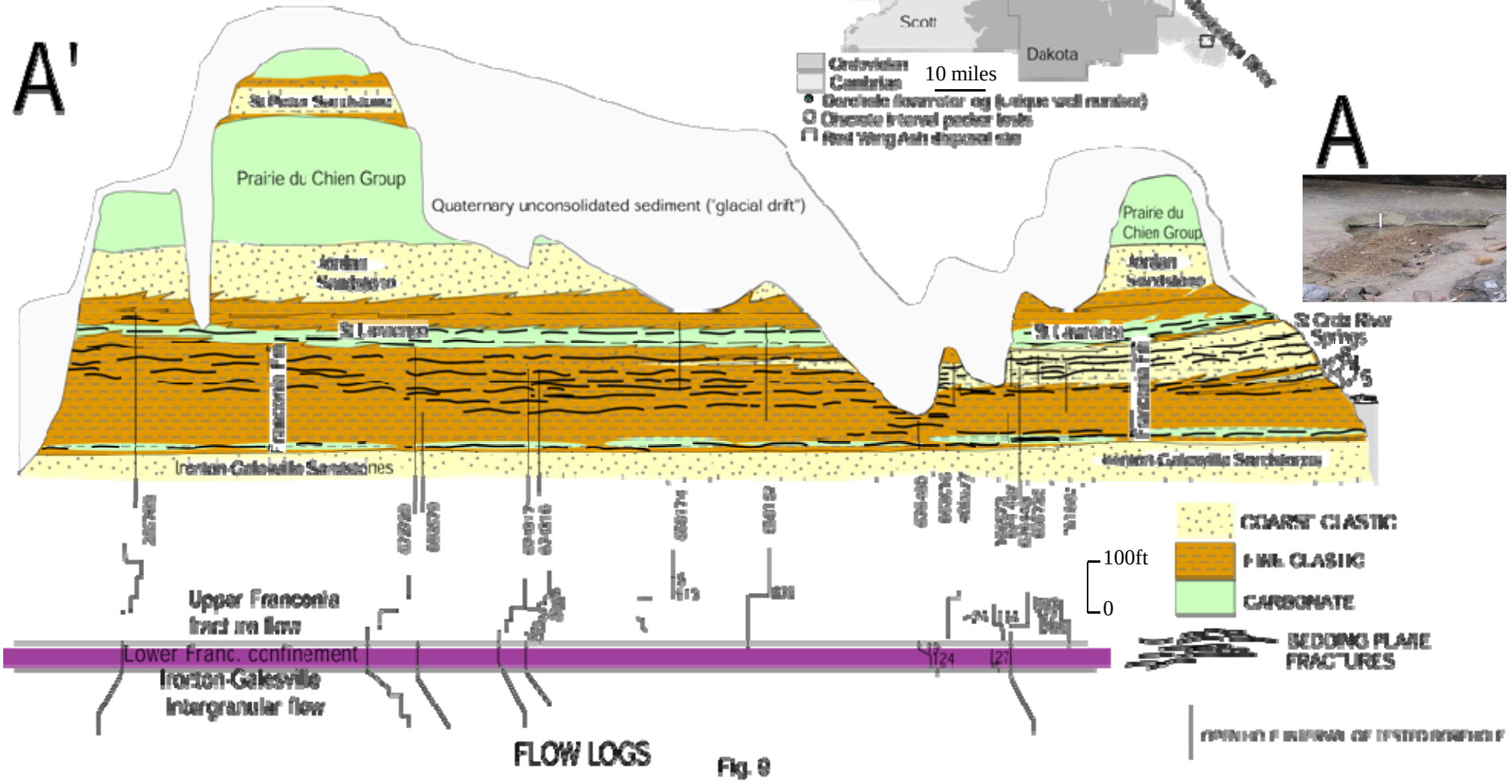
TRACKING BPF NETWORKS ACROSS SE MINNESOTA: ST PETER SANDSTONE

LAKE ELMO AREA, EASTERN METRO

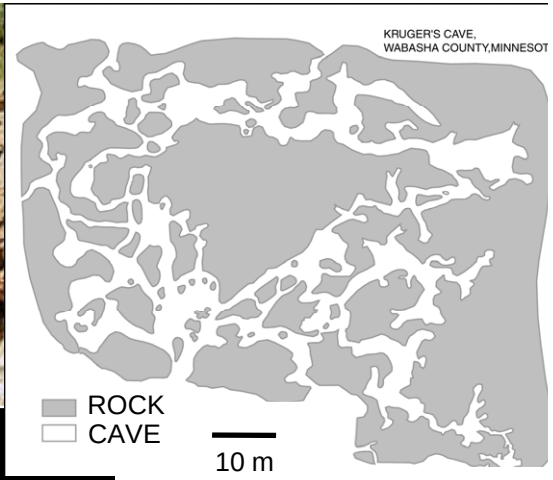


TRACKING BPF NETWORKS ACROSS SE MINNESOTA: FRANCONIA FORMATION



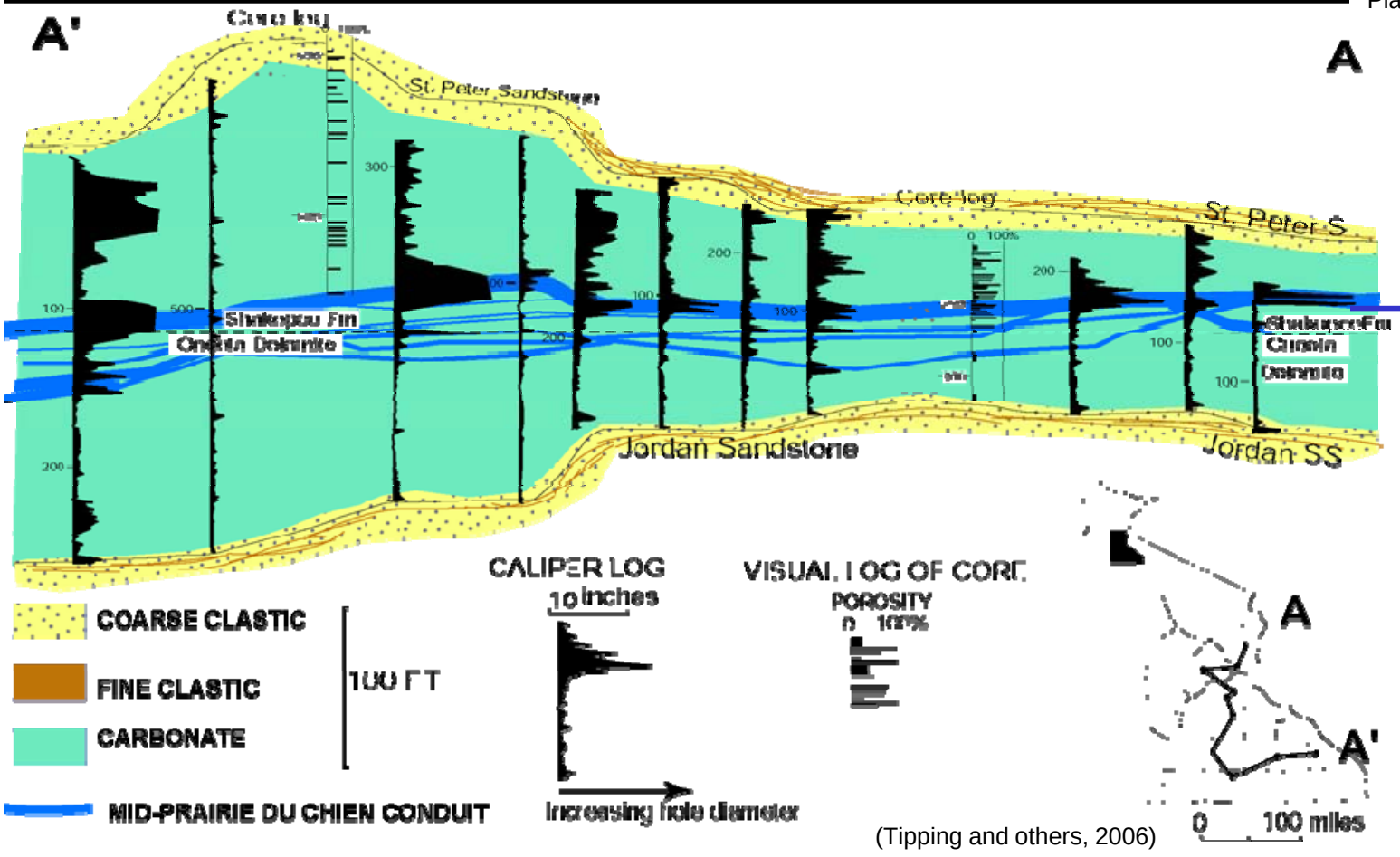


(Runkel and others, 2006)



Plan view of BPF/solution interval

TRACKING BPF NETWORKS ACROSS SE MINNESOTA: PRAIRIE DU CHIEN



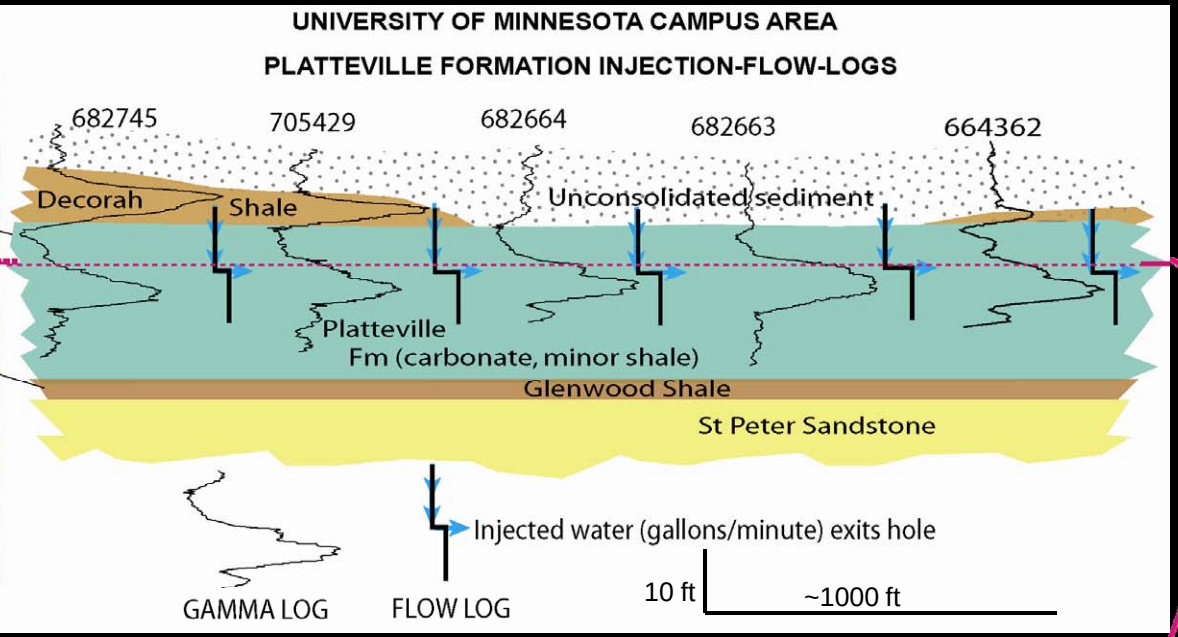
(Tipping and others, 2006)

[redacted]

DYE TRACES, FLOW, CONDUCTIVITY, TEMP AND VIDEO LOGS INDICATE SIGNFICANT CONDUIT

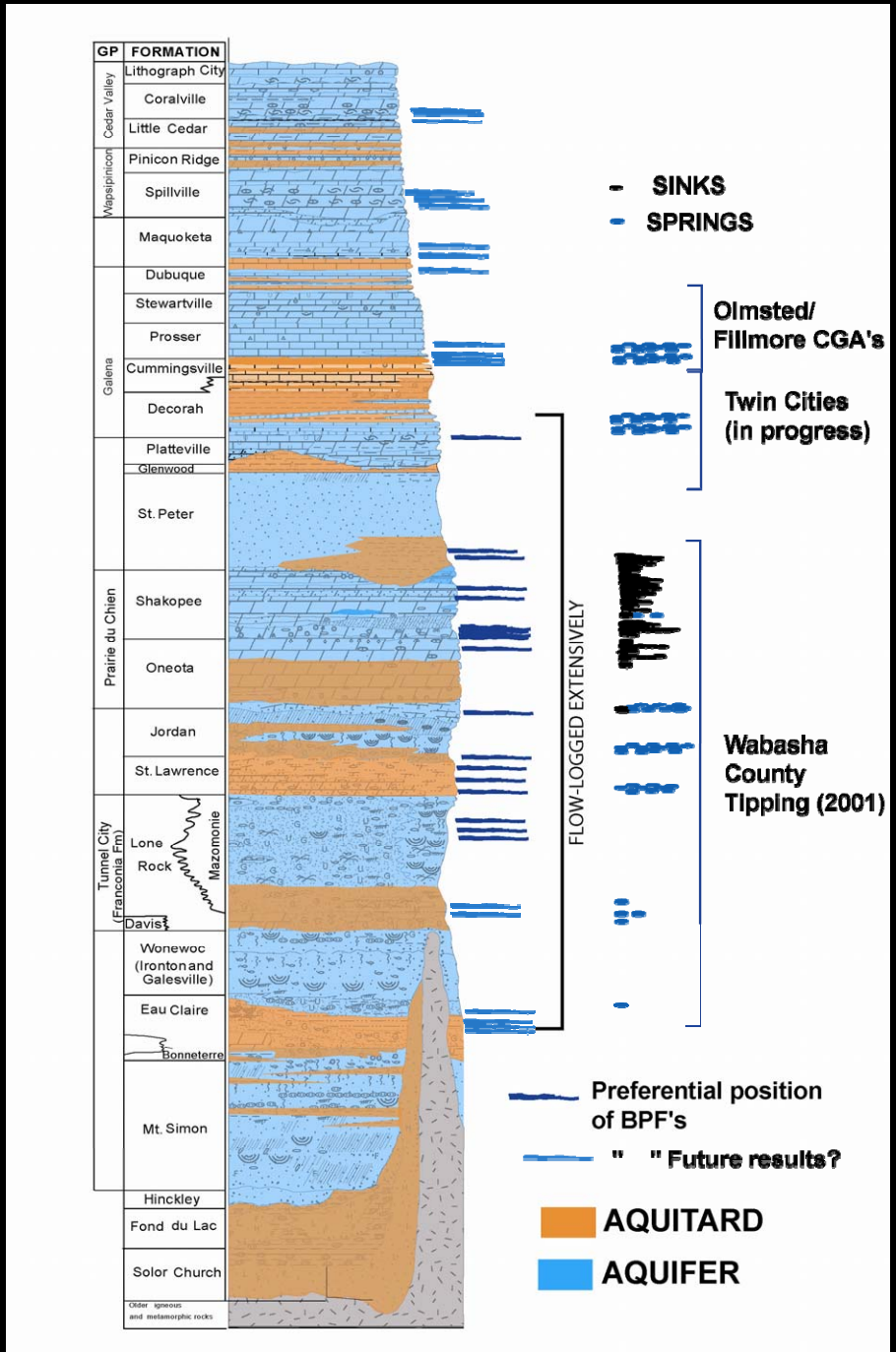
[redacted]

TRACKING BPF NETWORKS ACROSS SE MINNESOTA: PLATTEVILLE FM



Top of Hidden Falls Mbr Springs/strat link by Kelton Barr since 1980's

BPFS, SUMMARY: PREFERENTIAL STRATIGRAPHIC POSITIONS

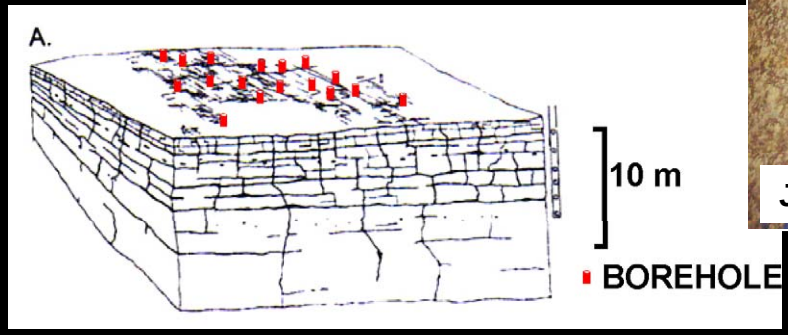


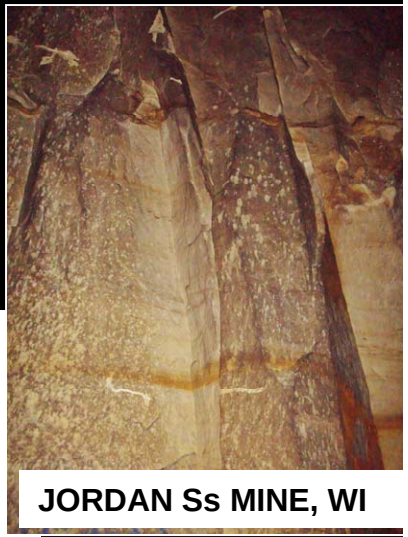
PART TWO: VERTICAL FRACTURES

COMMON IN ALL BEDROCK OUTCROPS
PRESENT IN DEEPER SUBSURFACE

ST LAWRENCE FM OUTCROP

“DIMINISHED” PROGRESSIVELY WITH INCREASING DISTANCE FROM BEDROCK SURFACE

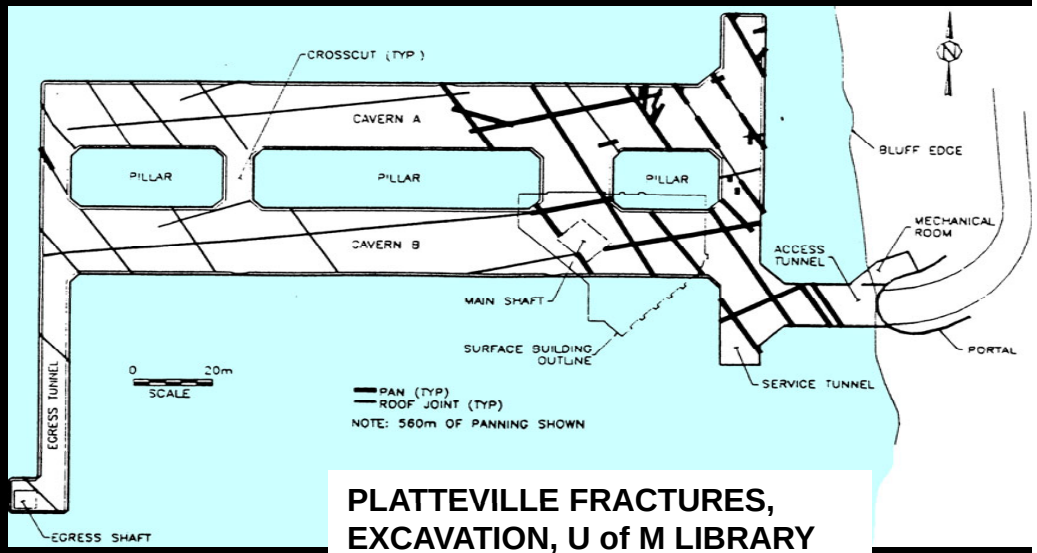




JORDAN Ss MINE, WI

IRONTON-GALESVILLE SANDSTONES, 395’, BROOKLYN PARK

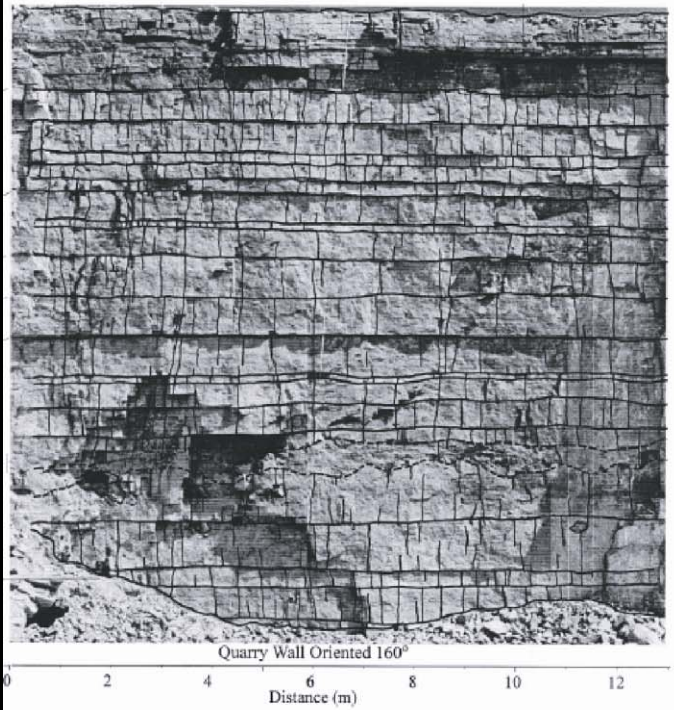
MT SIMON SANDSTONE, 564’ DEPTH, BROOKLYN PARK



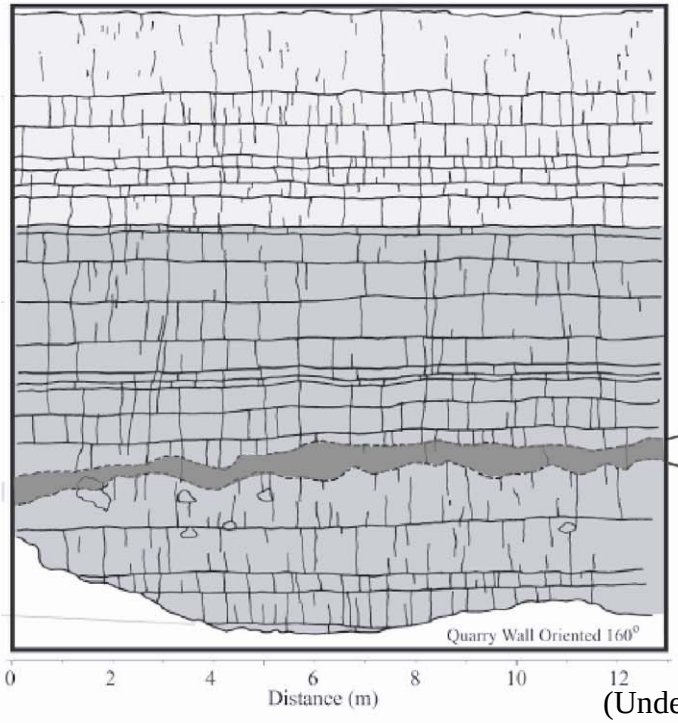
PLATTEVILLE FRACTURES, EXCAVATION, U of M LIBRARY

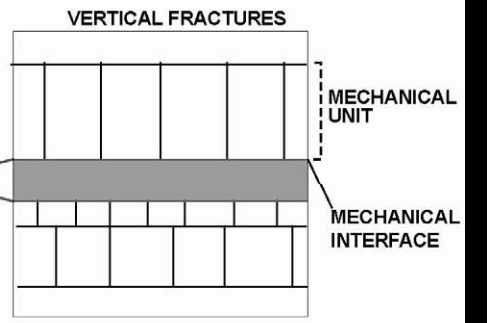
Maybe its not so much about where vertical fractures are….
……but instead, where they are not?

NORTH-EASTERN WISCONSIN



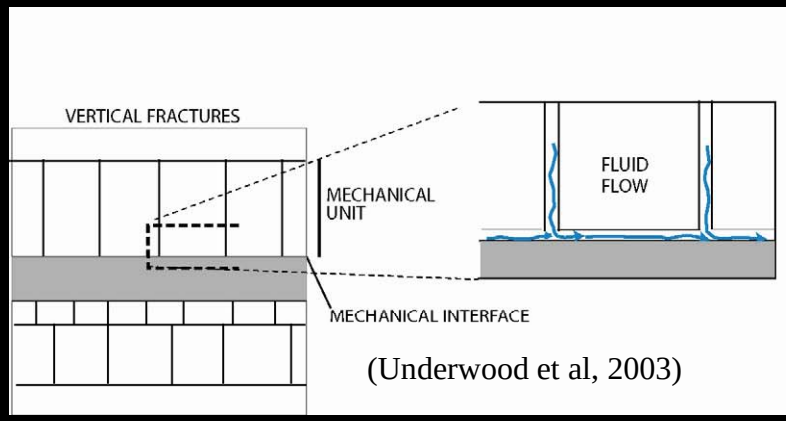
MECHANICAL STRATIGRAPHY





(Underwood et al, 2003)

POTENTIAL LINK TO STRAT POSITION AND ORIGIN OF BPF'S



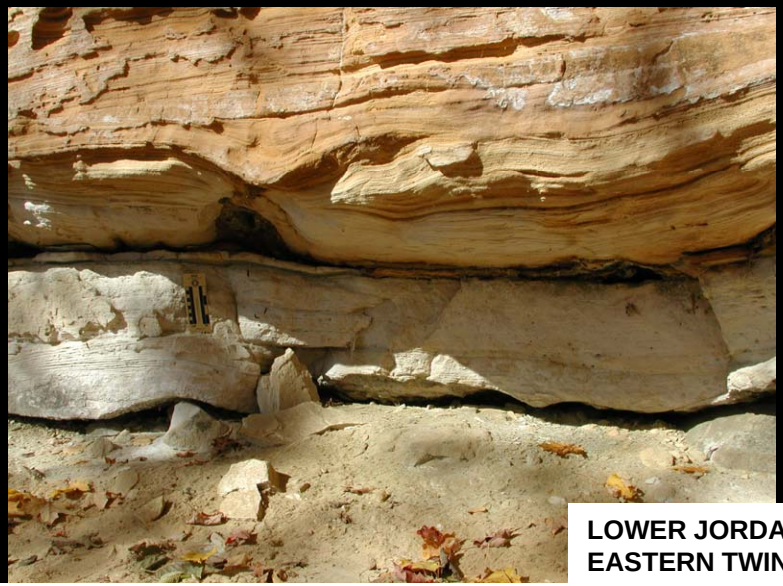
(Underwood et al, 2003)

PLATTEVILLE FM, TWIN CITIES METRO

Does preferential termination of vertical fractures correspond to preferential BPF development?

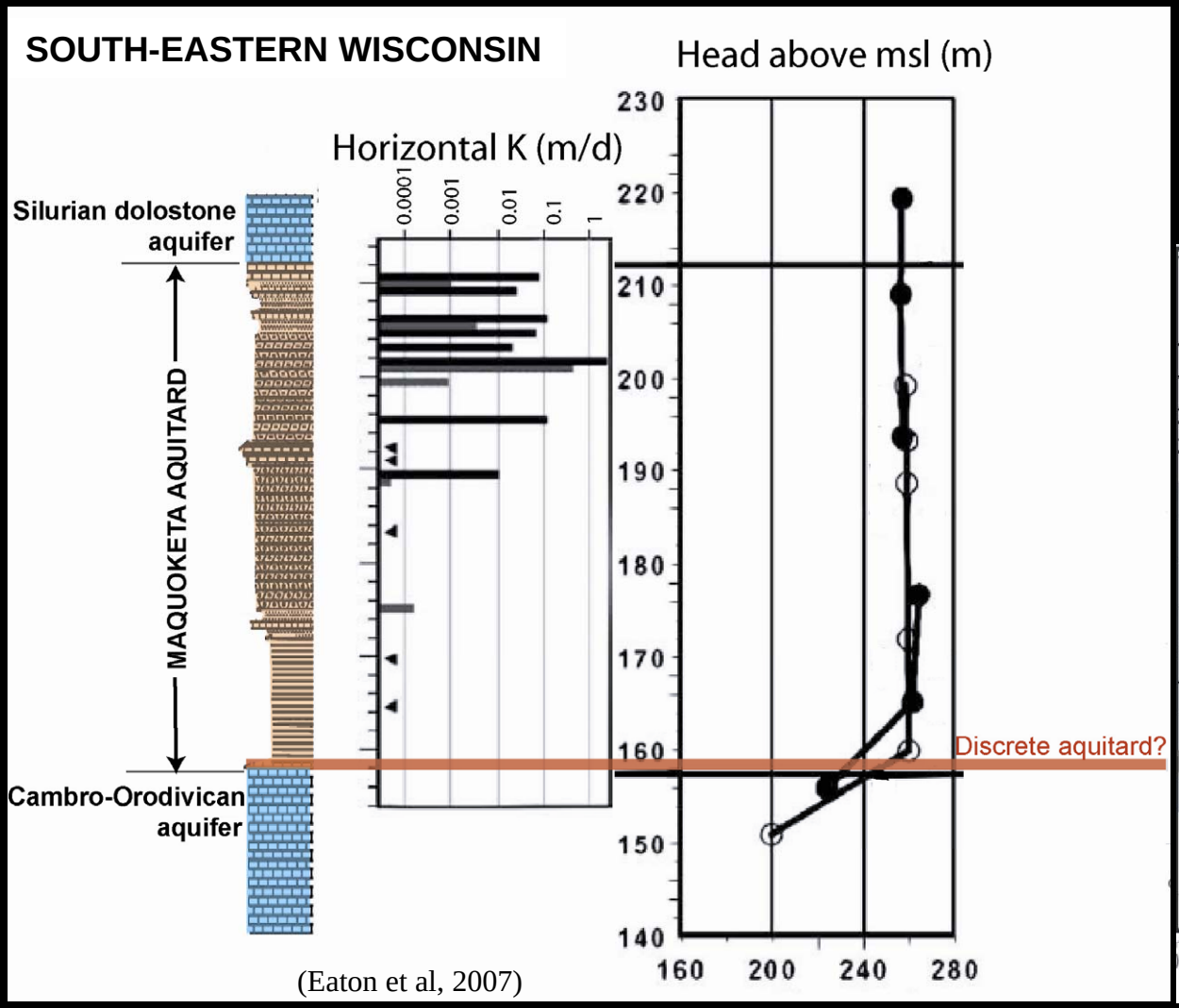
POTENTIAL LINK TO STRAT POSITION AND ORIGIN OF BPF'S?

Does preferential termination of vertical fractures correspond to preferential BPF development?

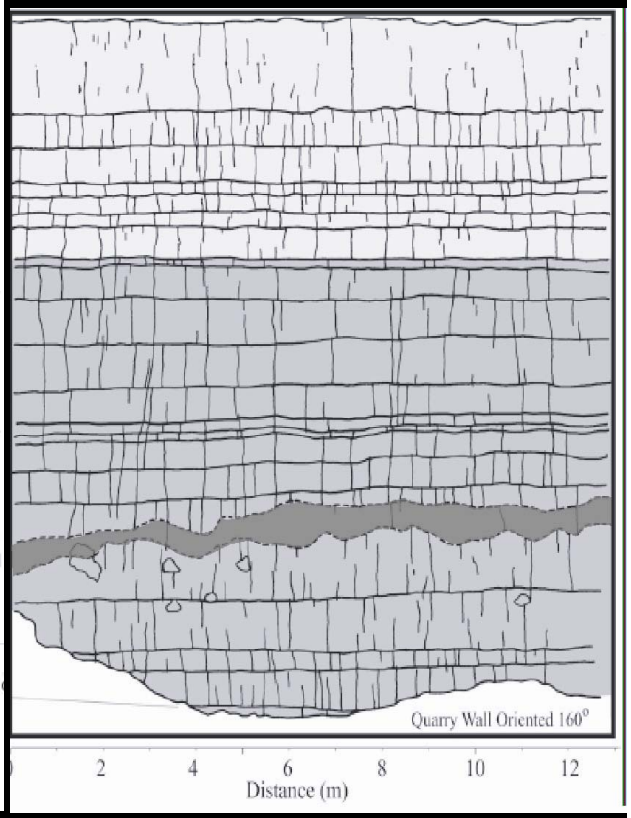


LOWER JORDAN SANDSTONE
EASTERN TWIN CITIES METRO

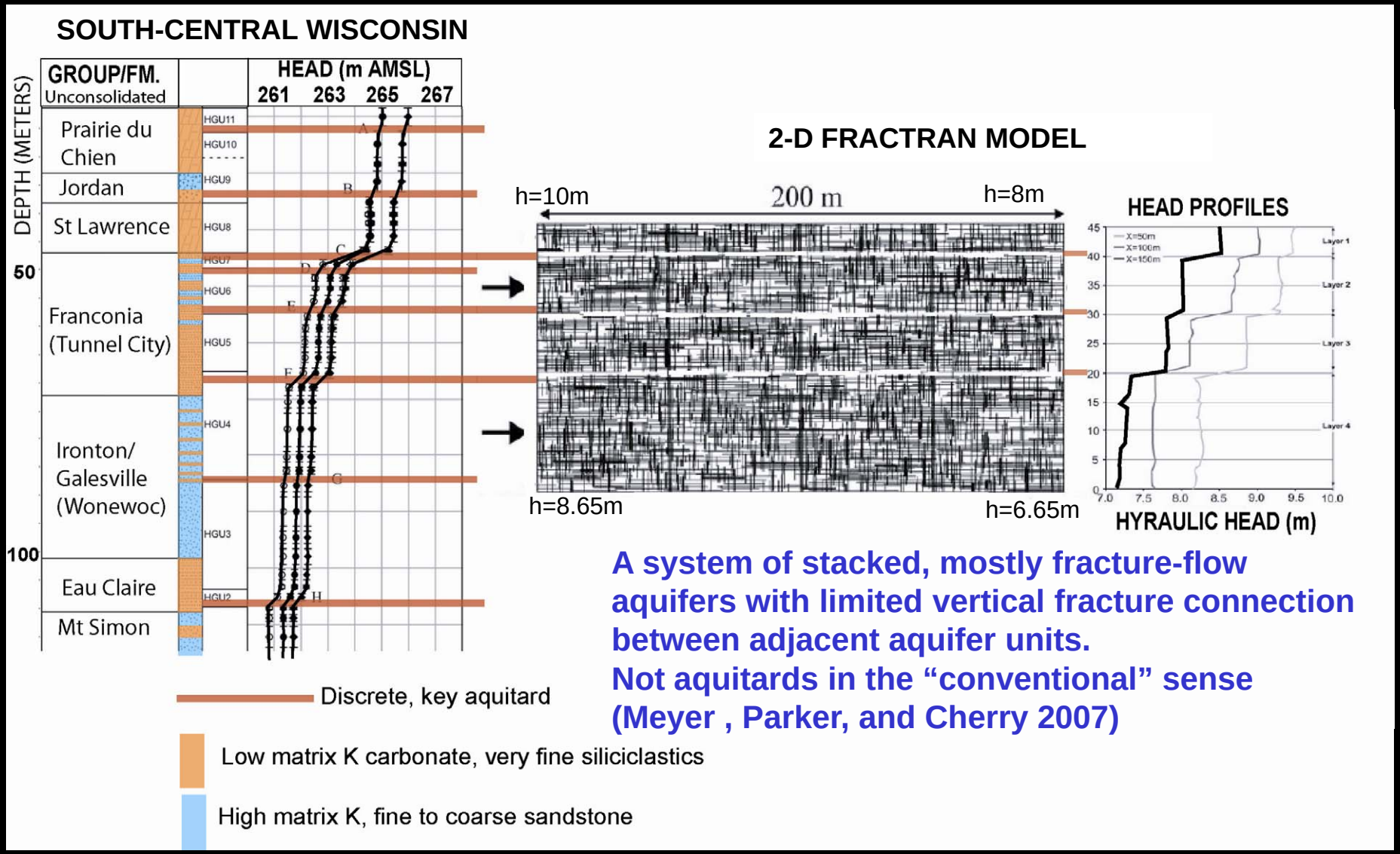
VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS



(Eaton et al, 2007)

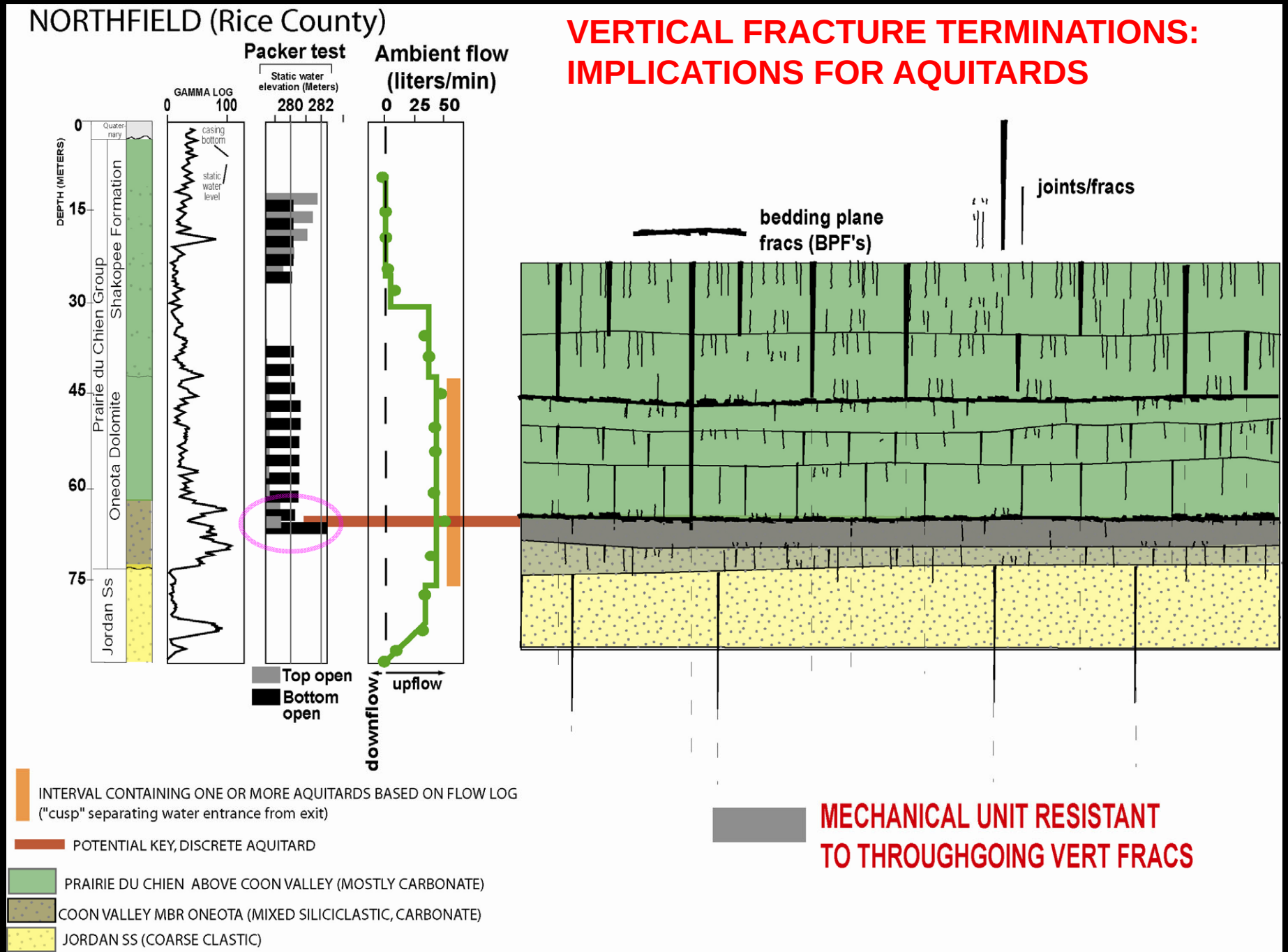


VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS

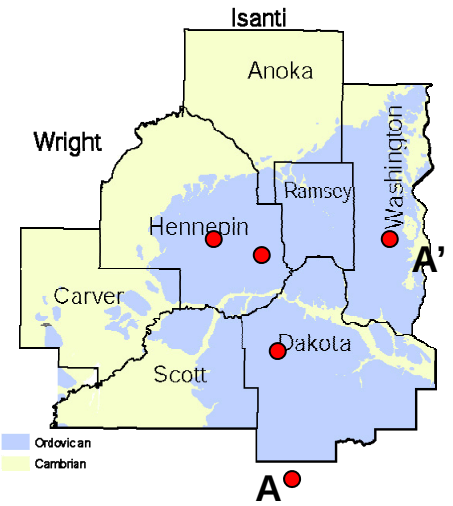


A system of stacked, mostly fracture-flow aquifers with limited vertical fracture connection between adjacent aquifer units.
Not aquitards in the "conventional" sense (Meyer , Parker, and Cherry 2007)

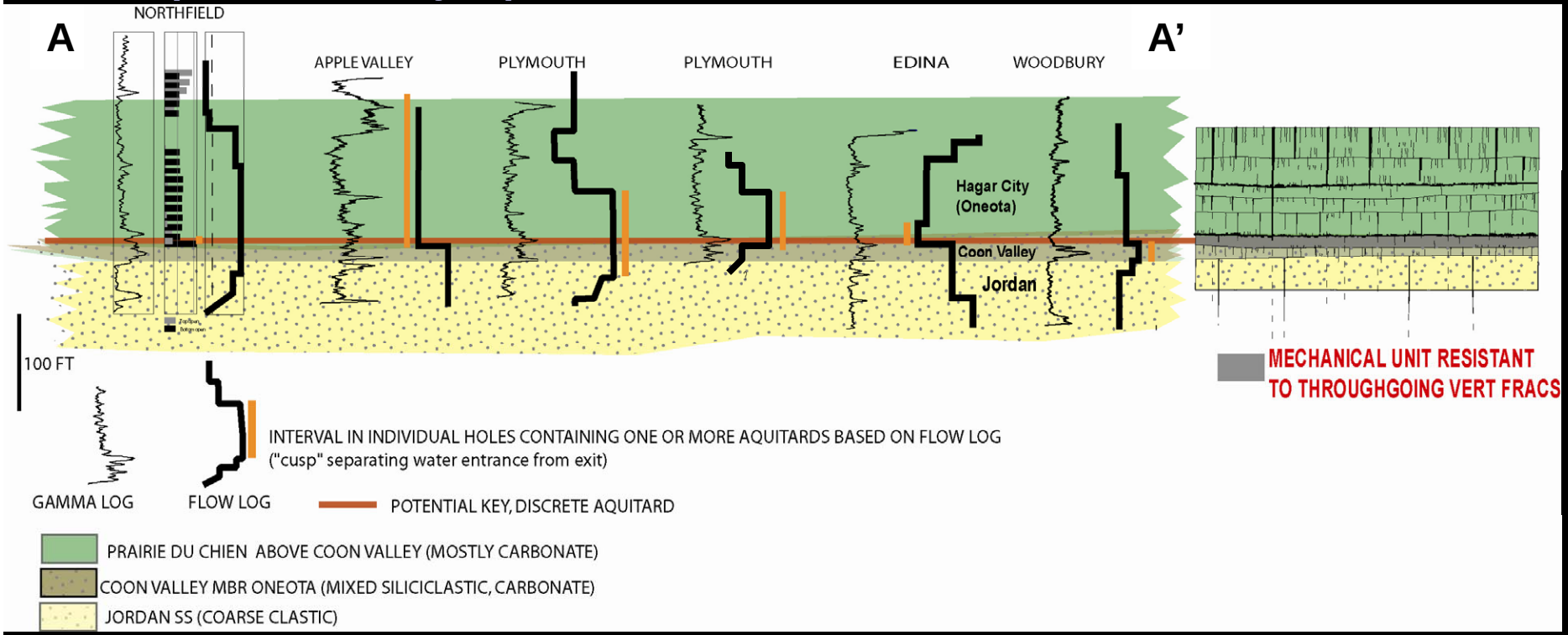
VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS



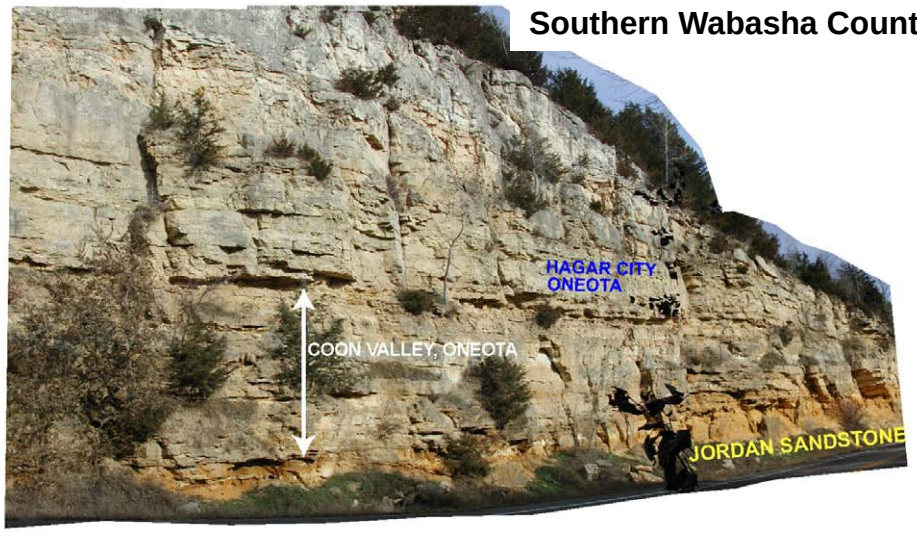
VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS



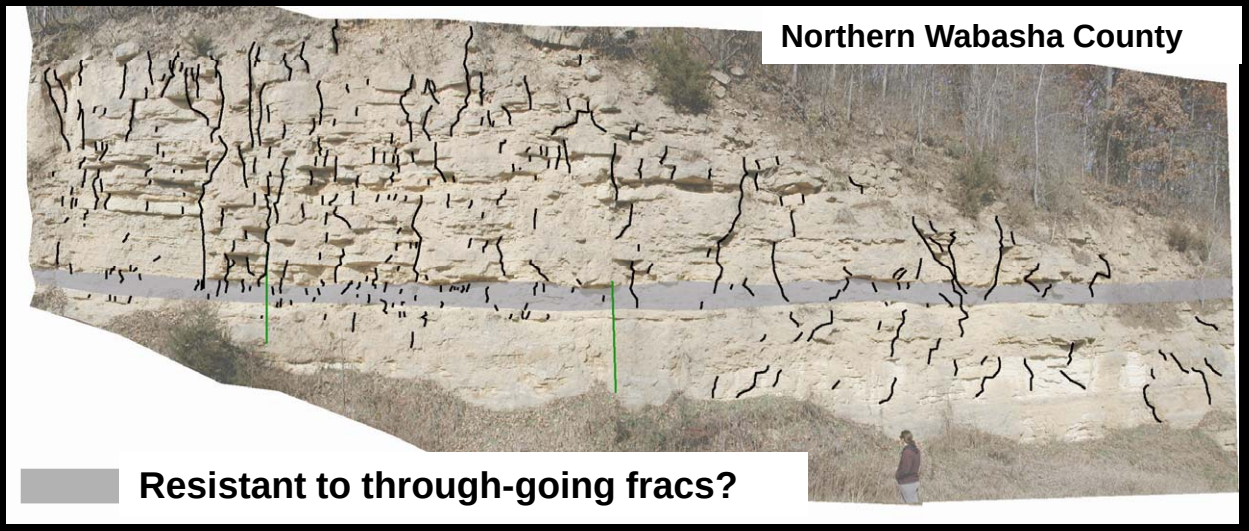
Do correlated flow logs tell us the position of key aquitards?



VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS

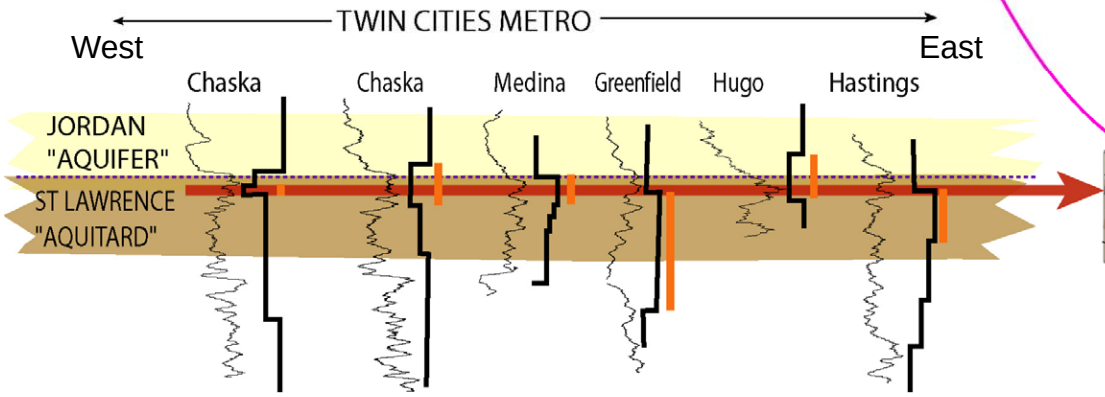


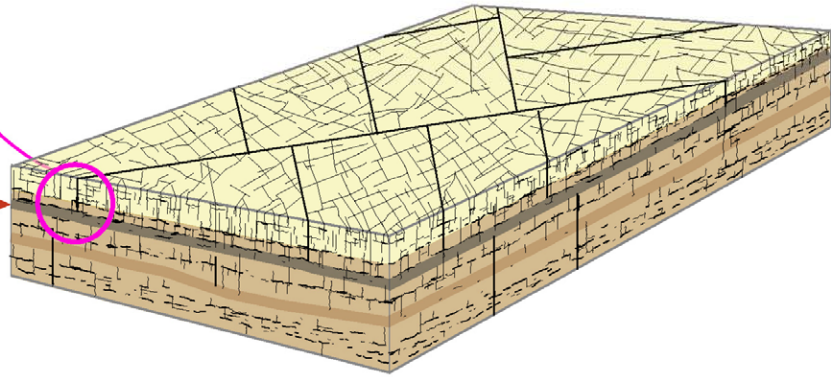
What can we learn from the outcrops?



IMPLICATIONS FOR AQUITARDS

Vertical joints with consistent lowermost Jordan terminations





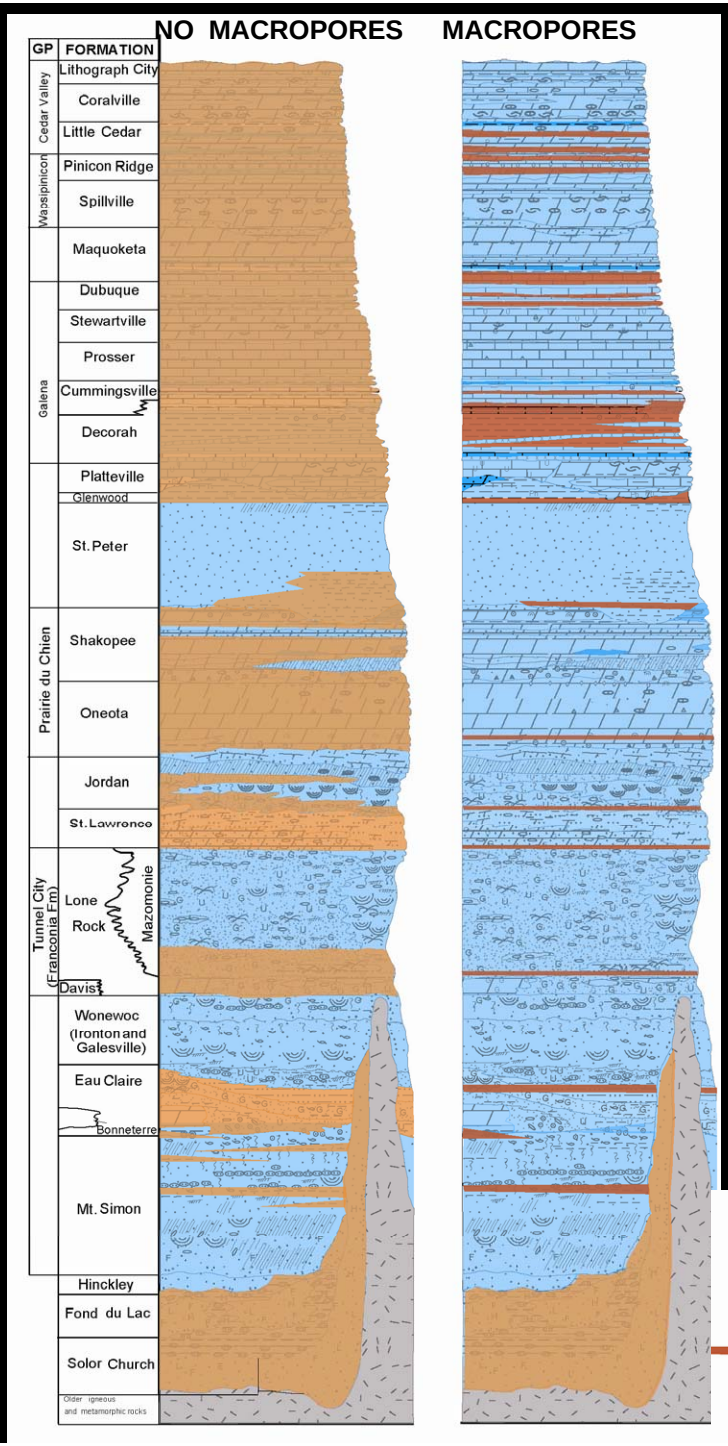
MECHANICAL UNIT RESISTANT TO THROUGHGOING VERT FRACS

NATURAL GAMMA LOG

EM BOREHOLE FLOW LOG

INTERVAL IN INDIVIDUAL HOLES CONTAINING ONE OR MORE AQUITARDS BASED ON FLOW LOG
("cusp" separating water entrance from exit)

POTENTIAL KEY, DISCRETE AQUITARD



VERTICAL FRACTURE TERMINATIONS: IMPLICATIONS FOR AQUITARDS

IS THE KEY TO AQUITARD INTEGRITY (AND THUS PROTECTION FROM CONTAMINANTS) THE PRESENCE OF VERY THIN, DISCRETE UNITS RESISTANT TO VERTICAL FRACTURES?

AQUITARD

AQUIFER

KEY, DISCRETE AQUITARD?

SUMMARY: “MAPPING” MACROPORES