Integrating Diverse High-Resolution Data Sets to Assess Aquitard Integrity in a DNAPL Contaminated Sedimentary Rock Aquifer System

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Providing Creative Solutions

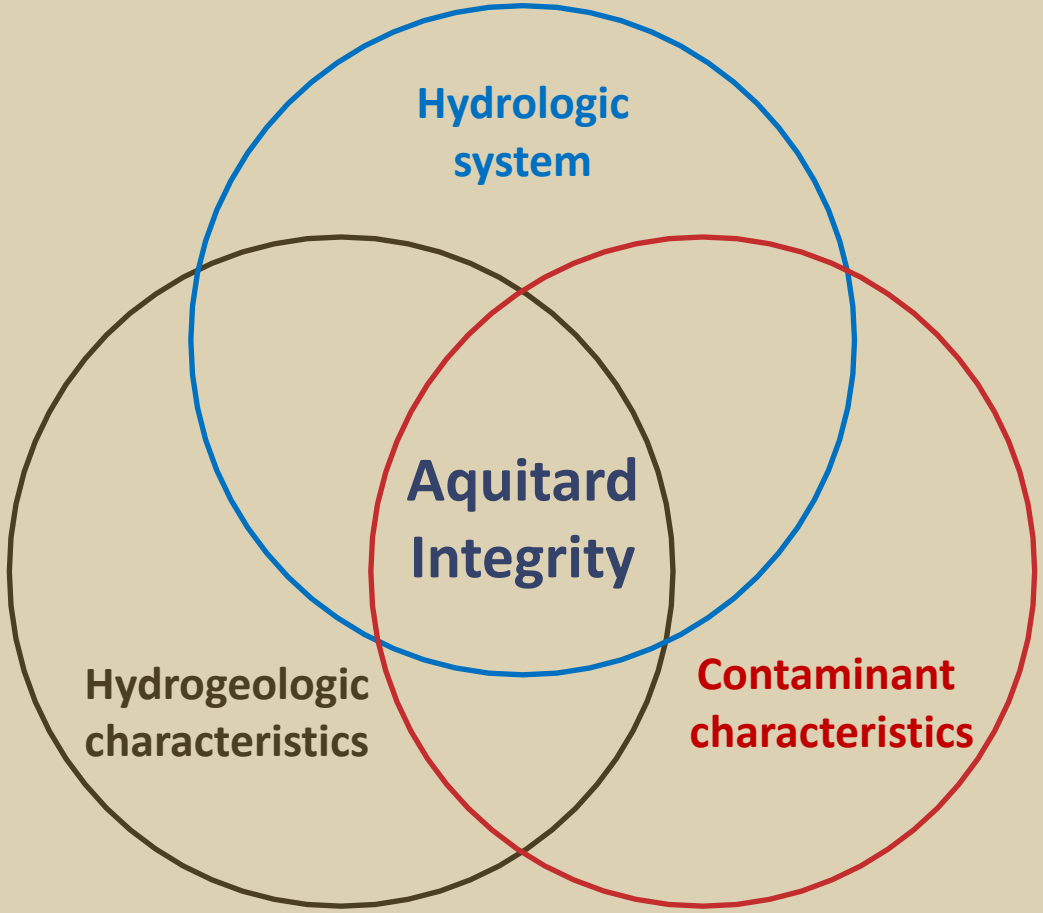
The UNIVERSITY CONSORTIUM

Westbay Instruments

GOLDER

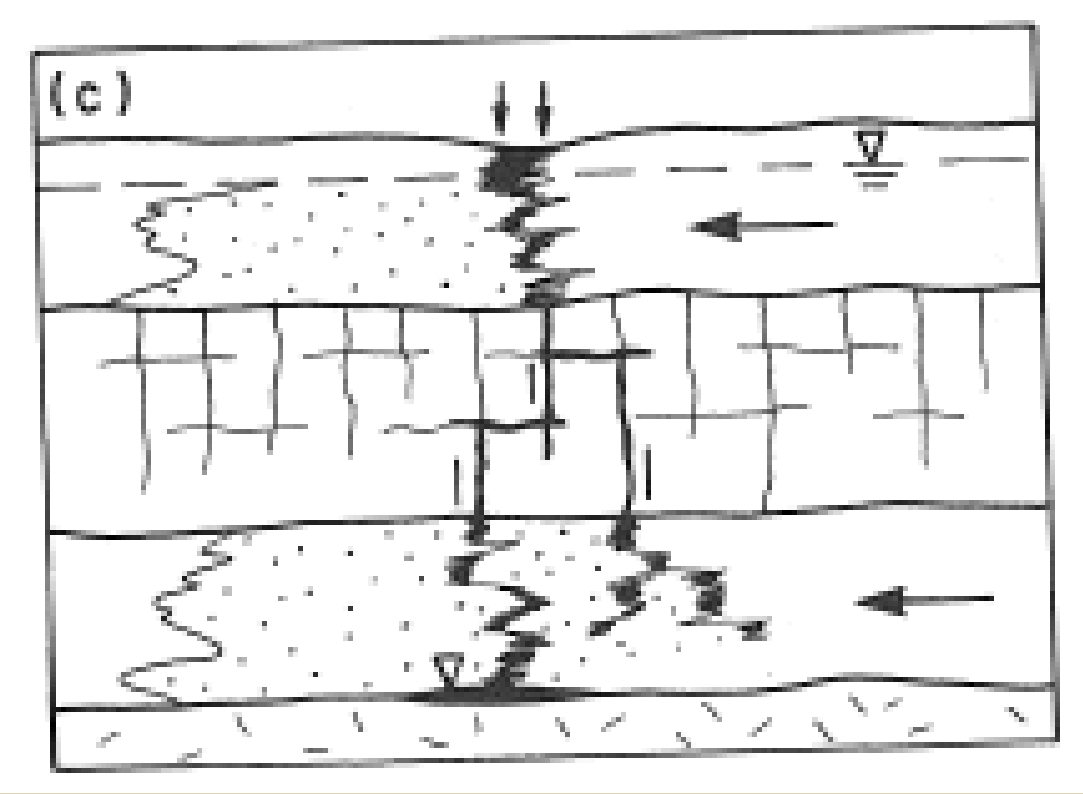
Aquitard Integrity

The degree to which an aquitard is protective of water quality in aquifers



Cherry et al. 2006, AwwaRF Report

Chlorinated Solvent DNAPLs Find Pathways Through Aquitards

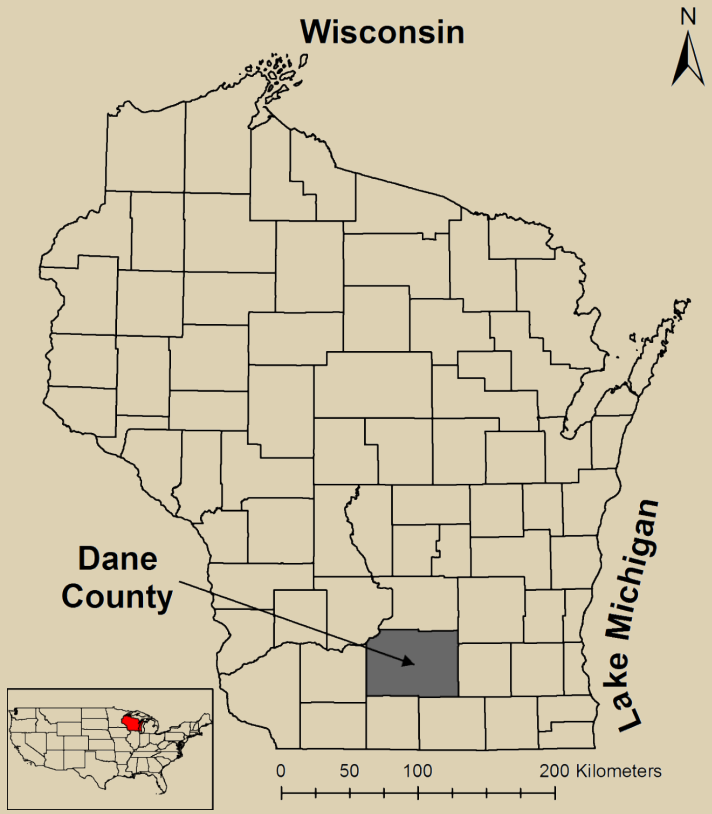


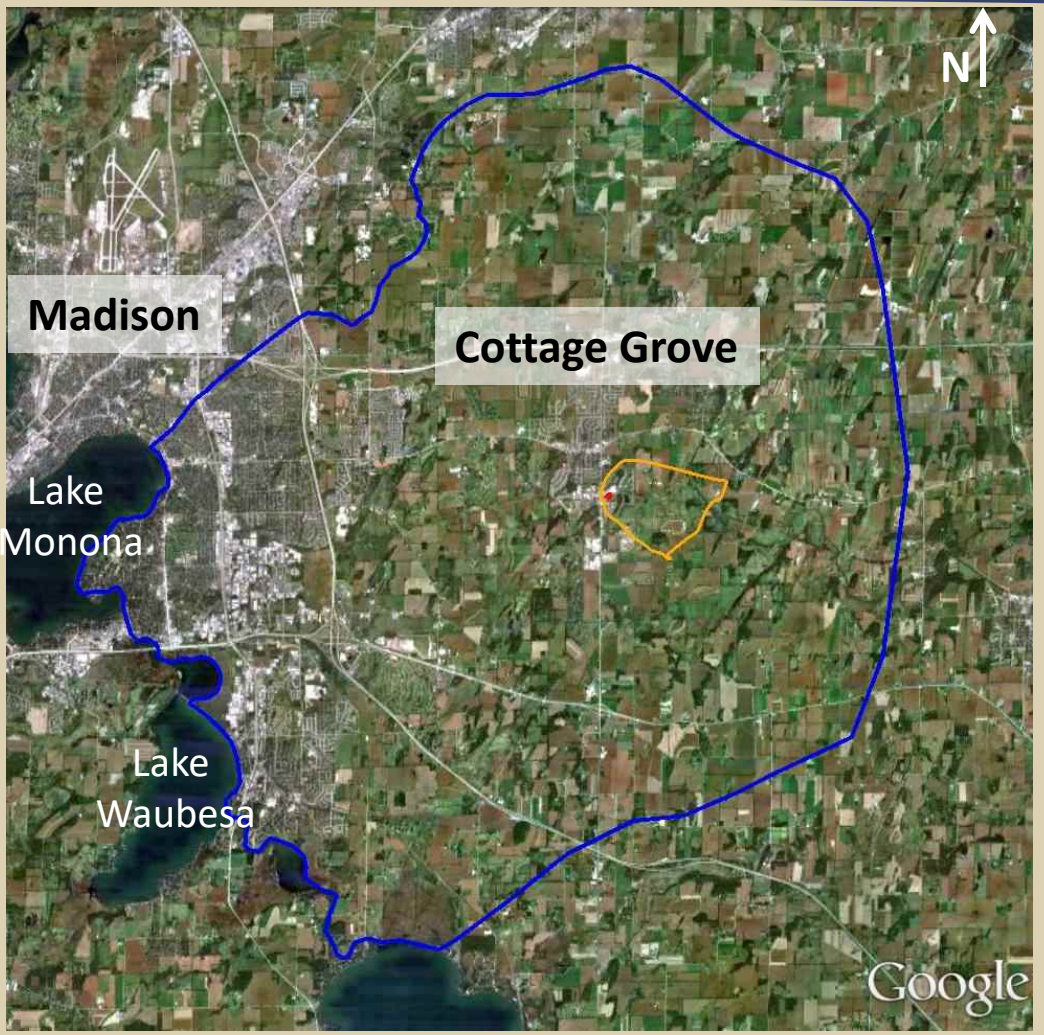
Pankow and Cherry, 1996

Chlorinated solvent DNAPLs can enter small pores/fractures allowing them to migrate to great depths because they:

- are much heavier than water
- have low viscosities
- have low interfacial tensions

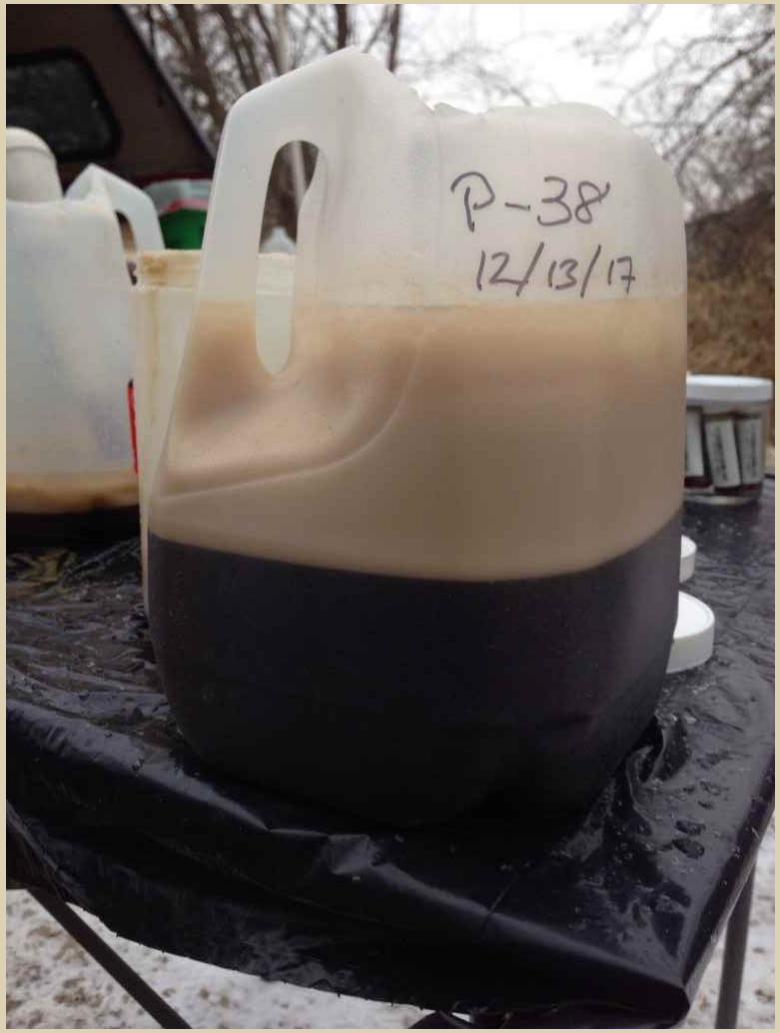
DNAPL Contamination in a Sedimentary Rock Aquifer System





- DNAPL source zone
- Max extent dissolved phase plume
- Flow model domain

Mixed Organic Contaminants

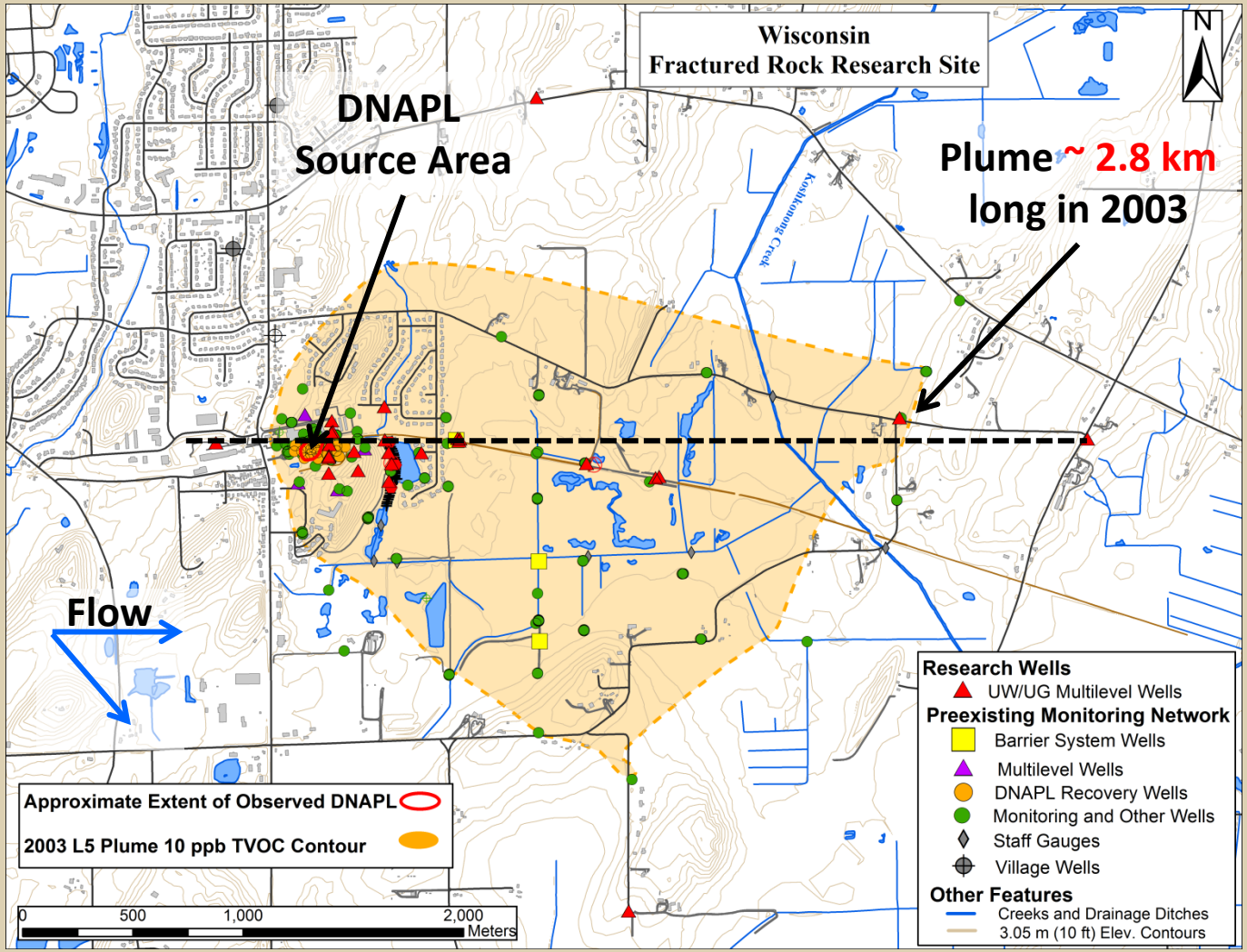


- Chlorinated solvents
- Benzene, toluene, xylenes
- Ketones

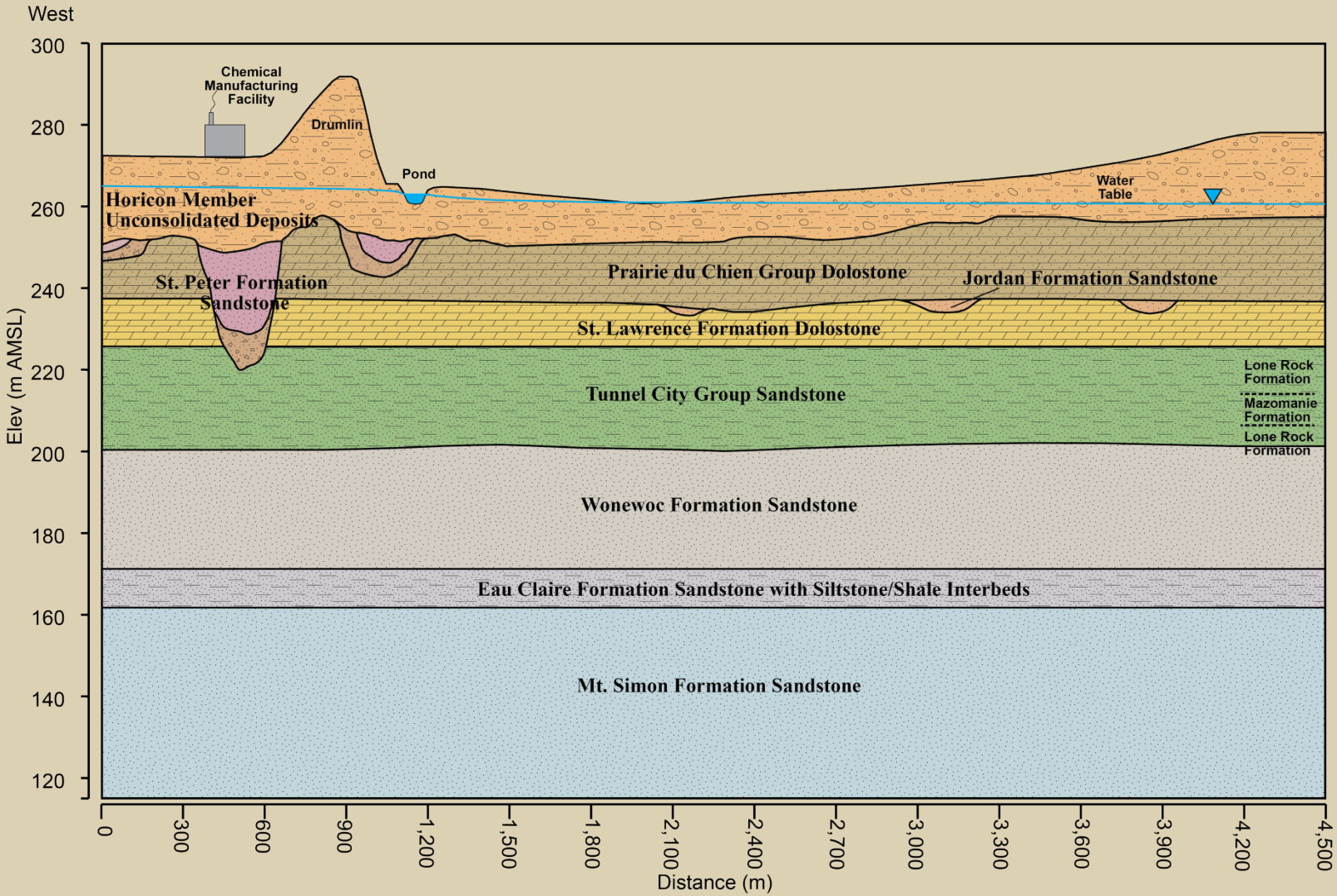
Mixture is a *DNAPL*

Dense Non-aqueous Phase Liquid

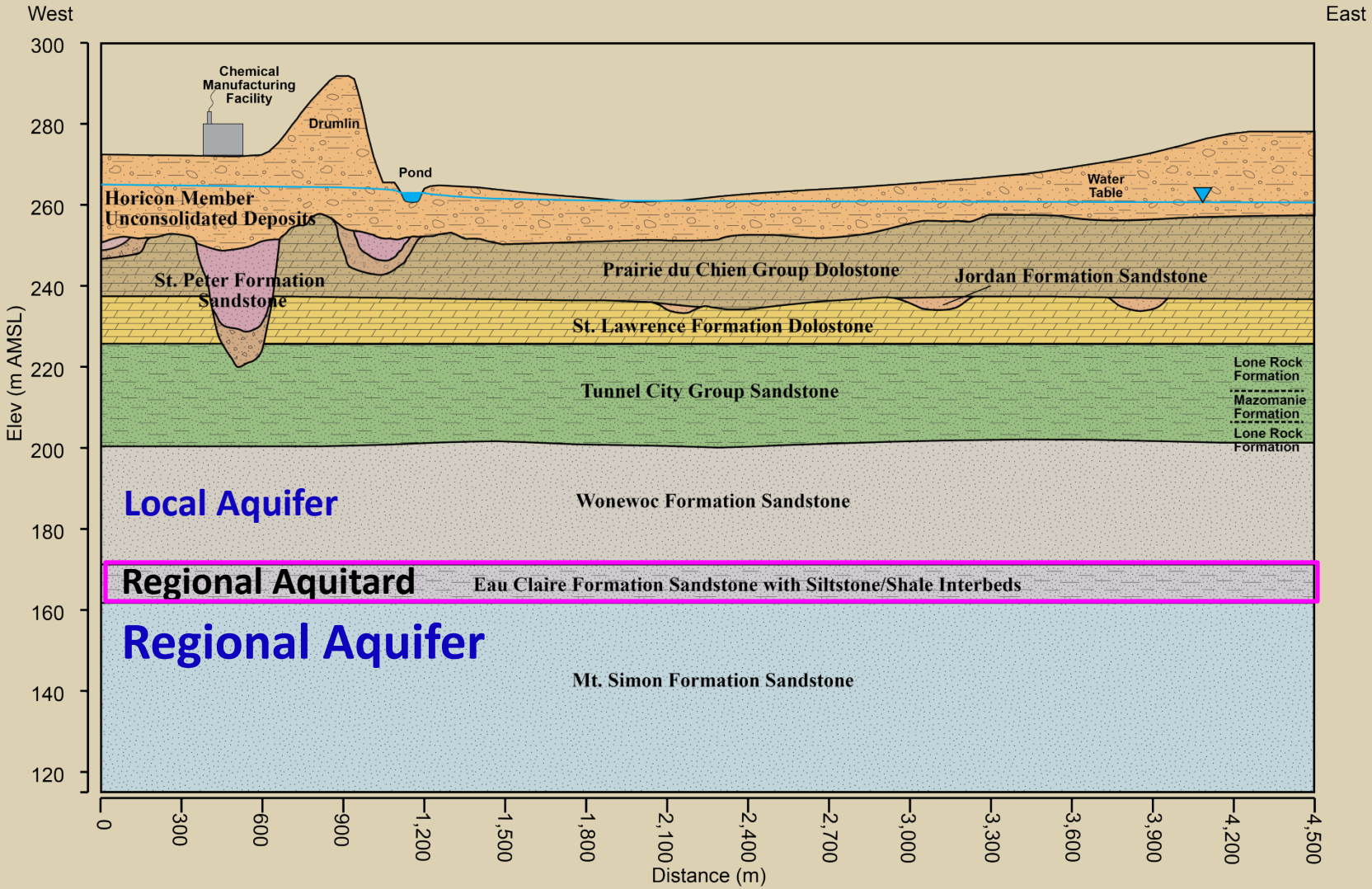
Mixed Organic Contaminants DNAPL Source Zone and Plume



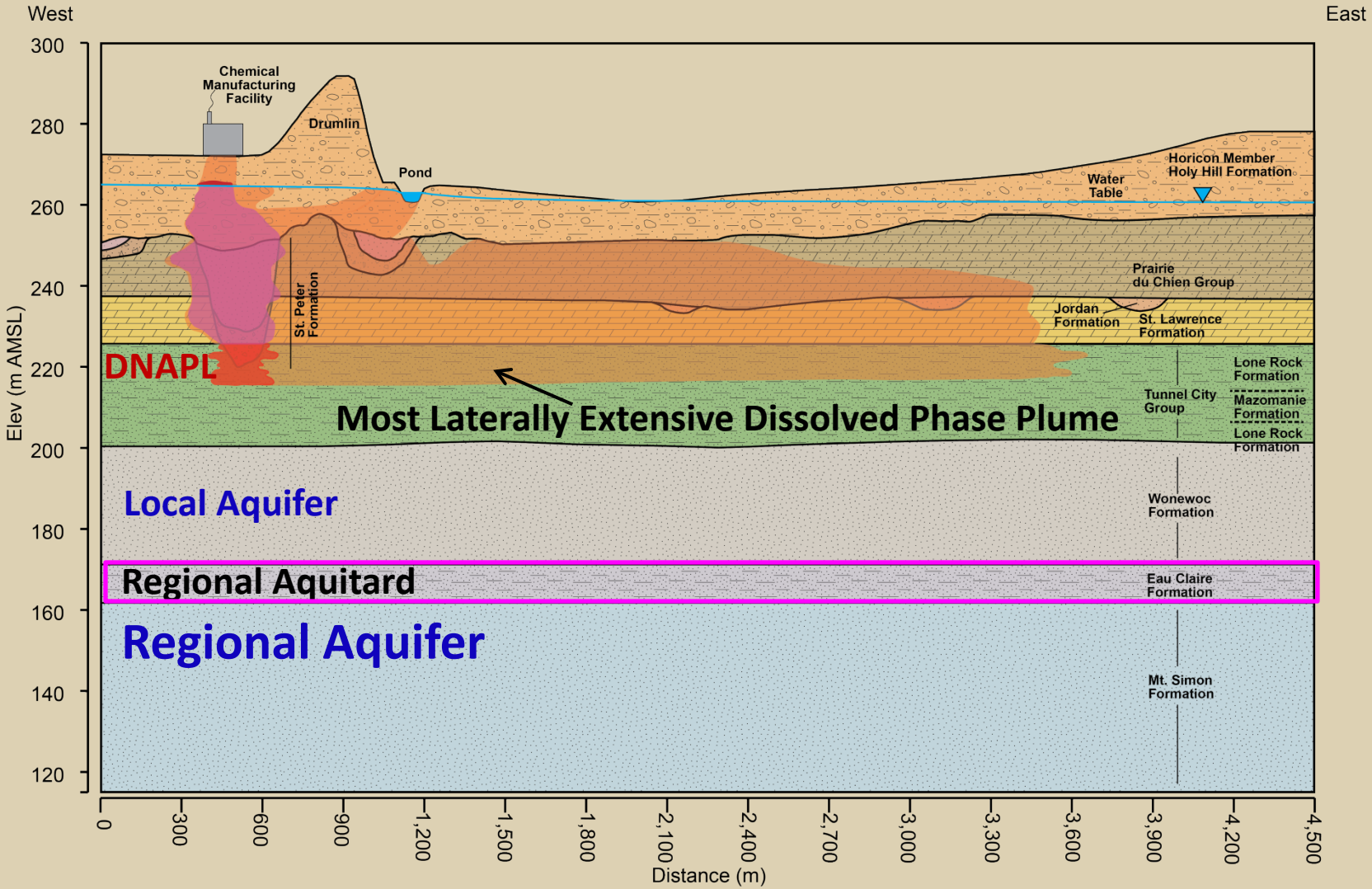
Lithostratigraphy



Portion of the Eau Claire Formation Recognized as a Regional Aquitard



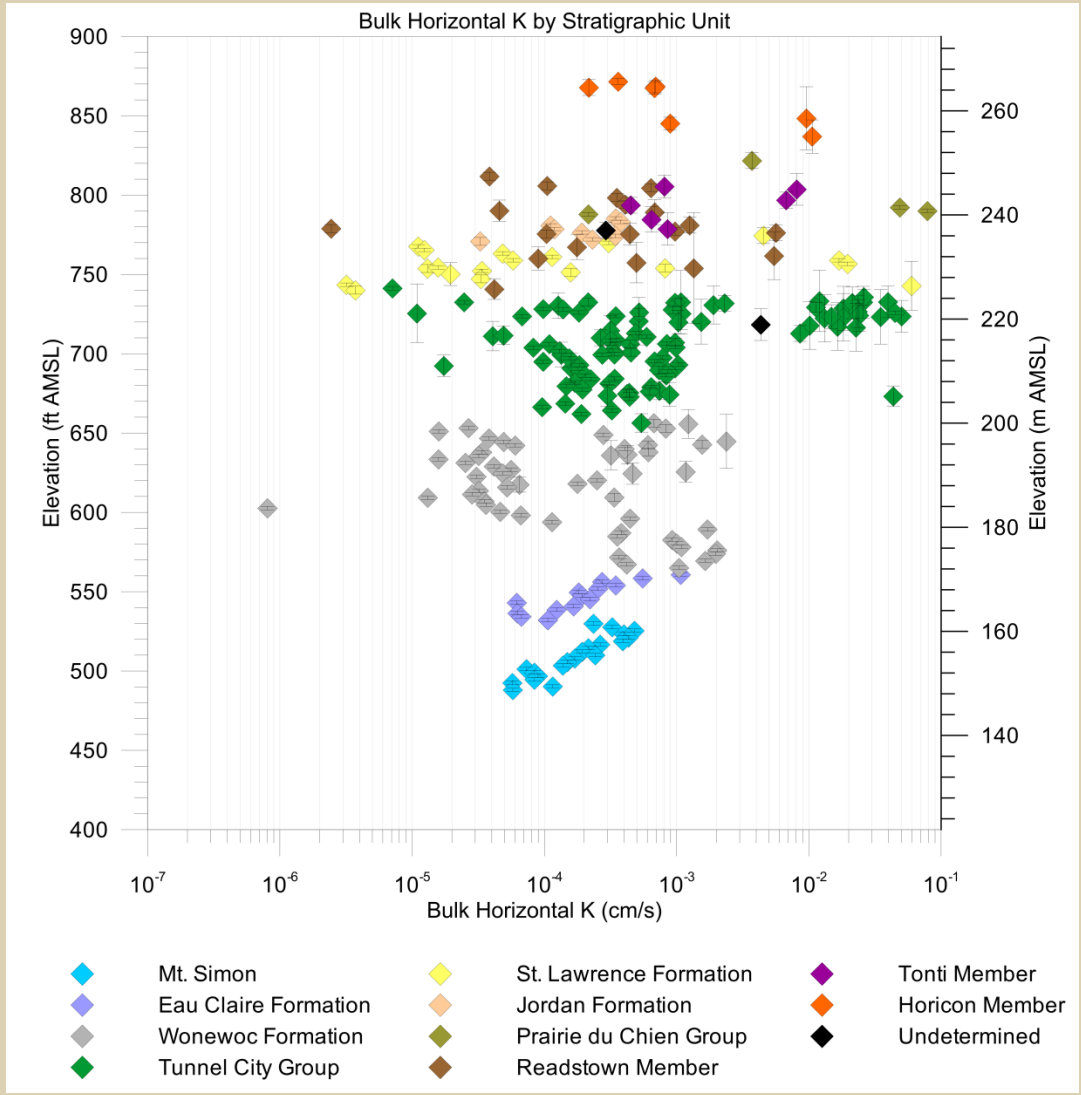
Schematic Contaminant Distribution



Research Questions

- Why did the DNAPL stop its downward migration?
- How many high integrity aquitards with respect to DNAPL occur between the contamination and the regional aquifer?
- What features create high integrity aquitards with respect to DNAPL in sedimentary rock systems?

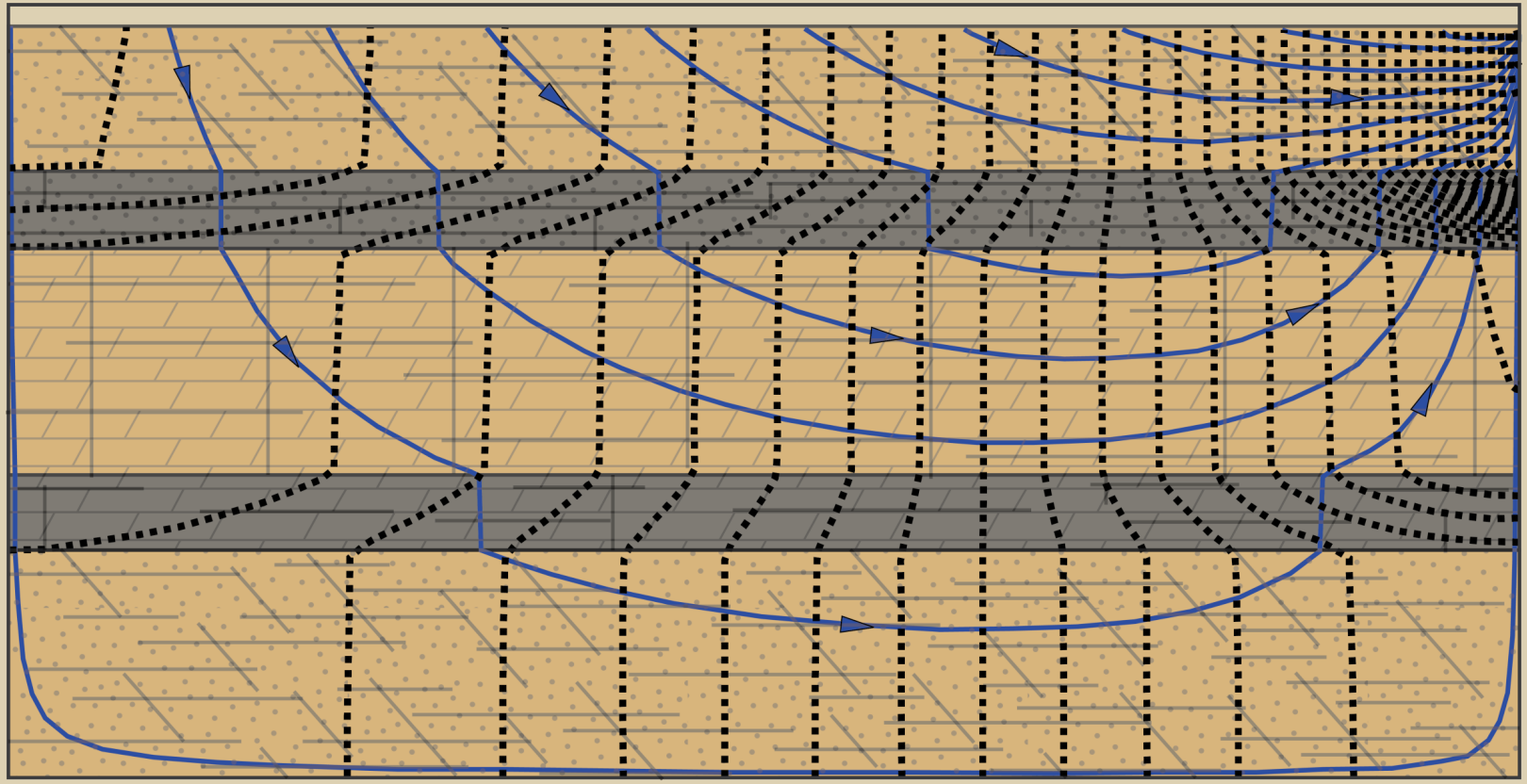
Aquitard Units Difficult to Identify from Bulk K Measurements



- Bulk K estimates from slug tests and pumping tests
- Results represent the **horizontal component** of K
- Bulk K_h not effective for identifying aquitards

Approach

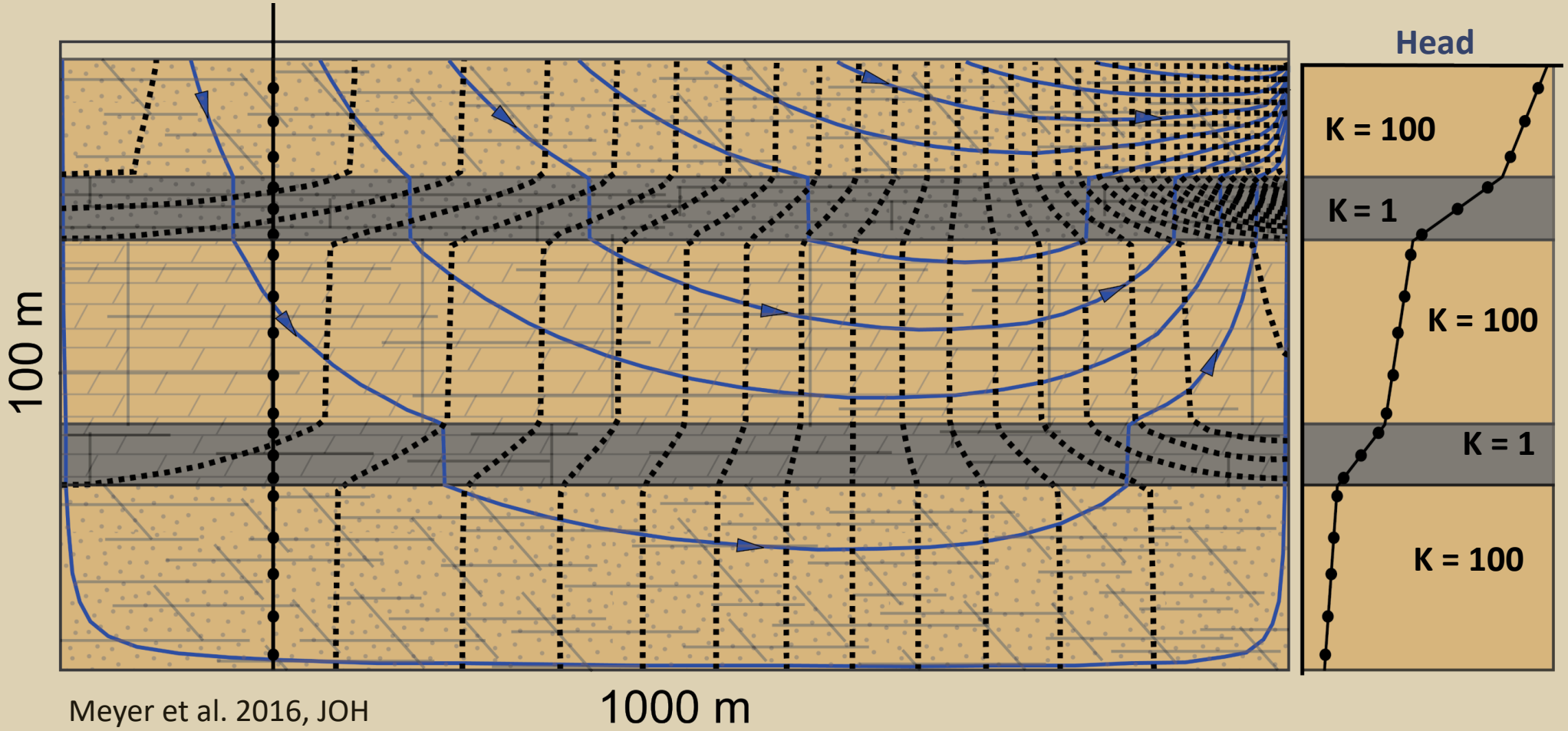
The hydraulic head distribution is a reflection of the K distribution



Meyer et al. 2016, JOH

Approach

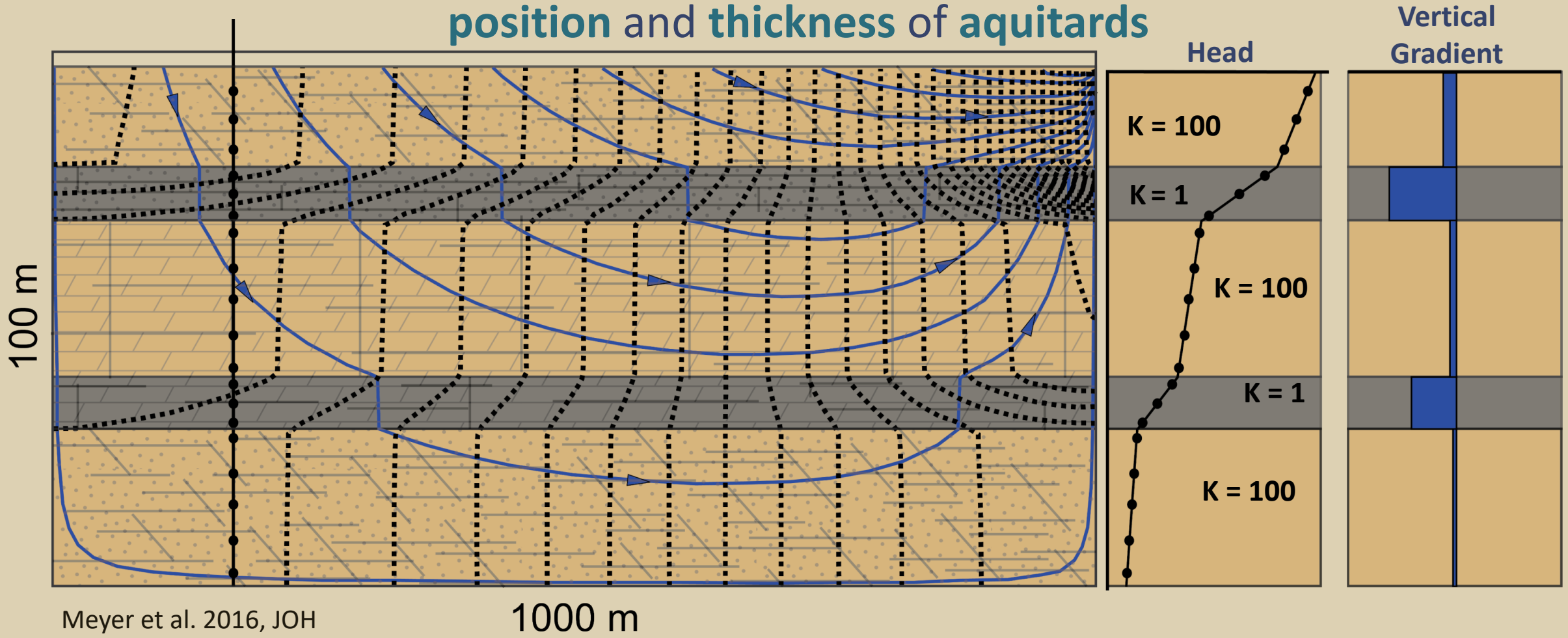
Collect high resolution head profiles



Meyer et al. 2016, JOH

Approach

Use high resolution vertical gradient profiles to identify the **position** and **thickness** of **aquitards**



Meyer et al. 2016, JOH

Approach

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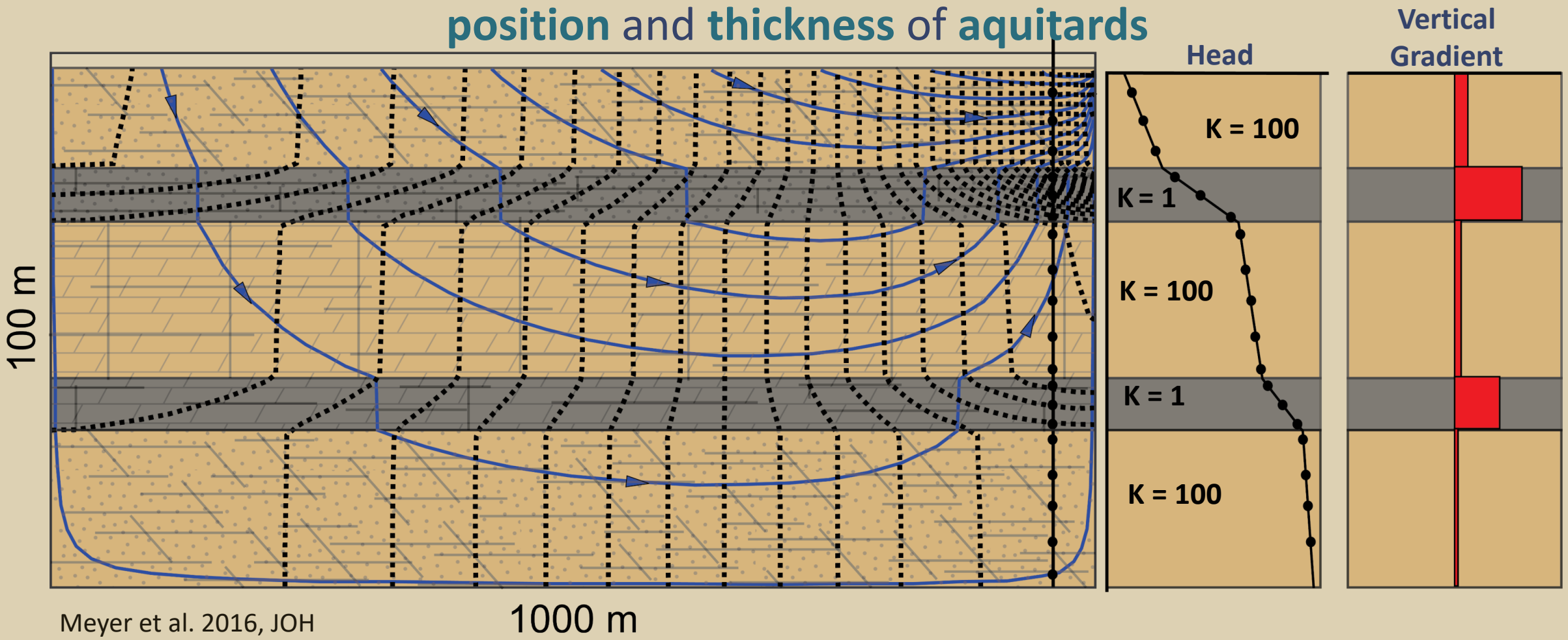
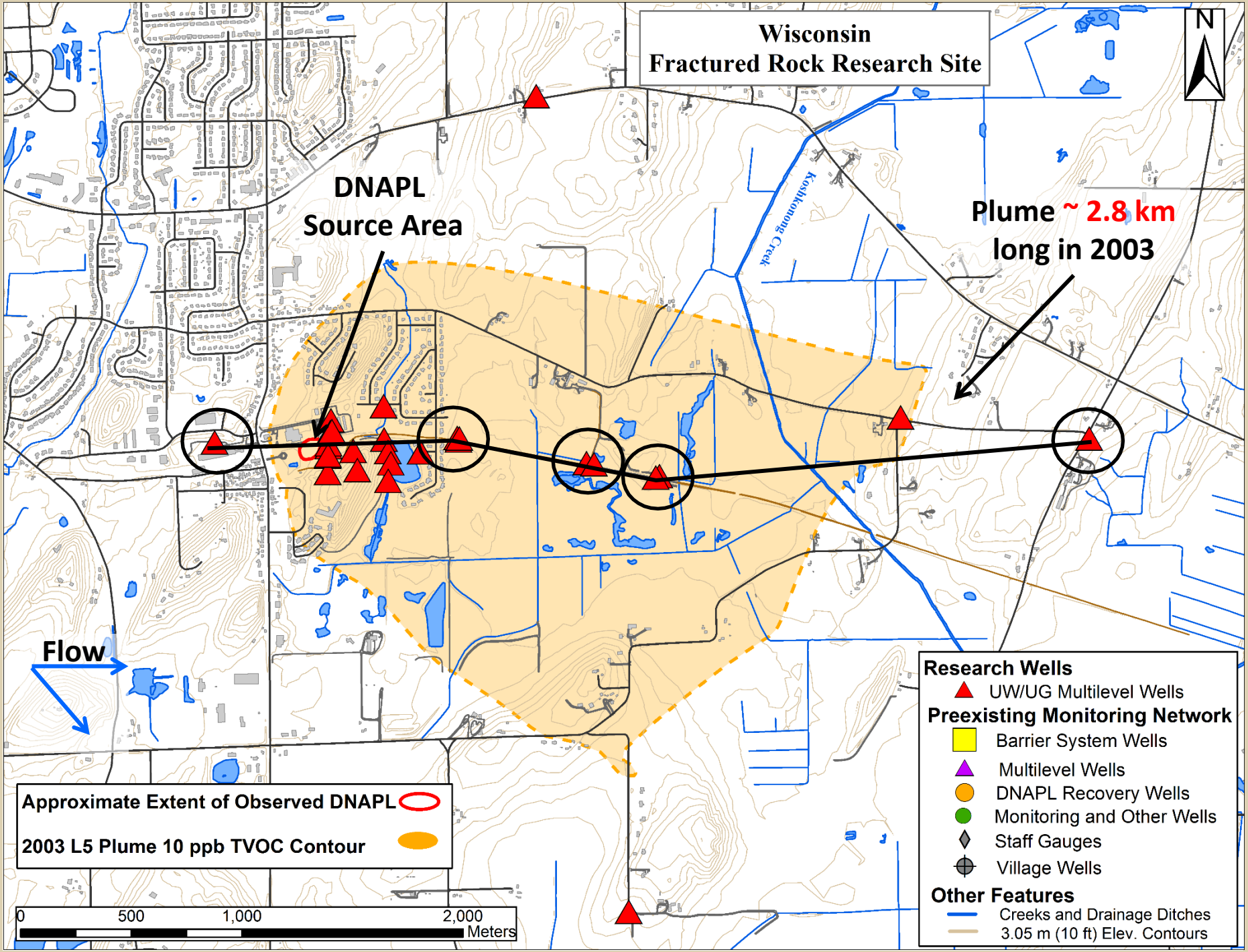
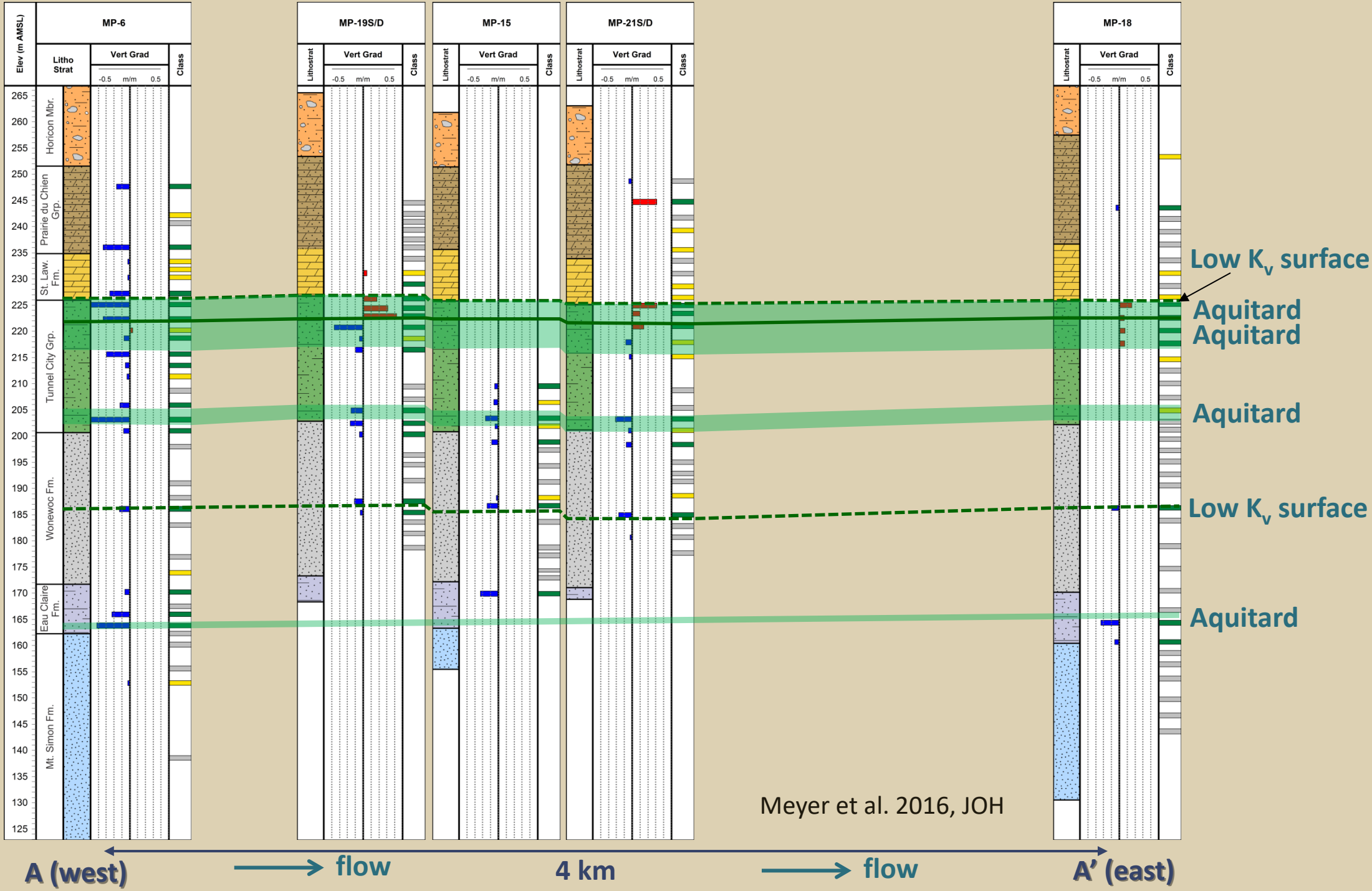
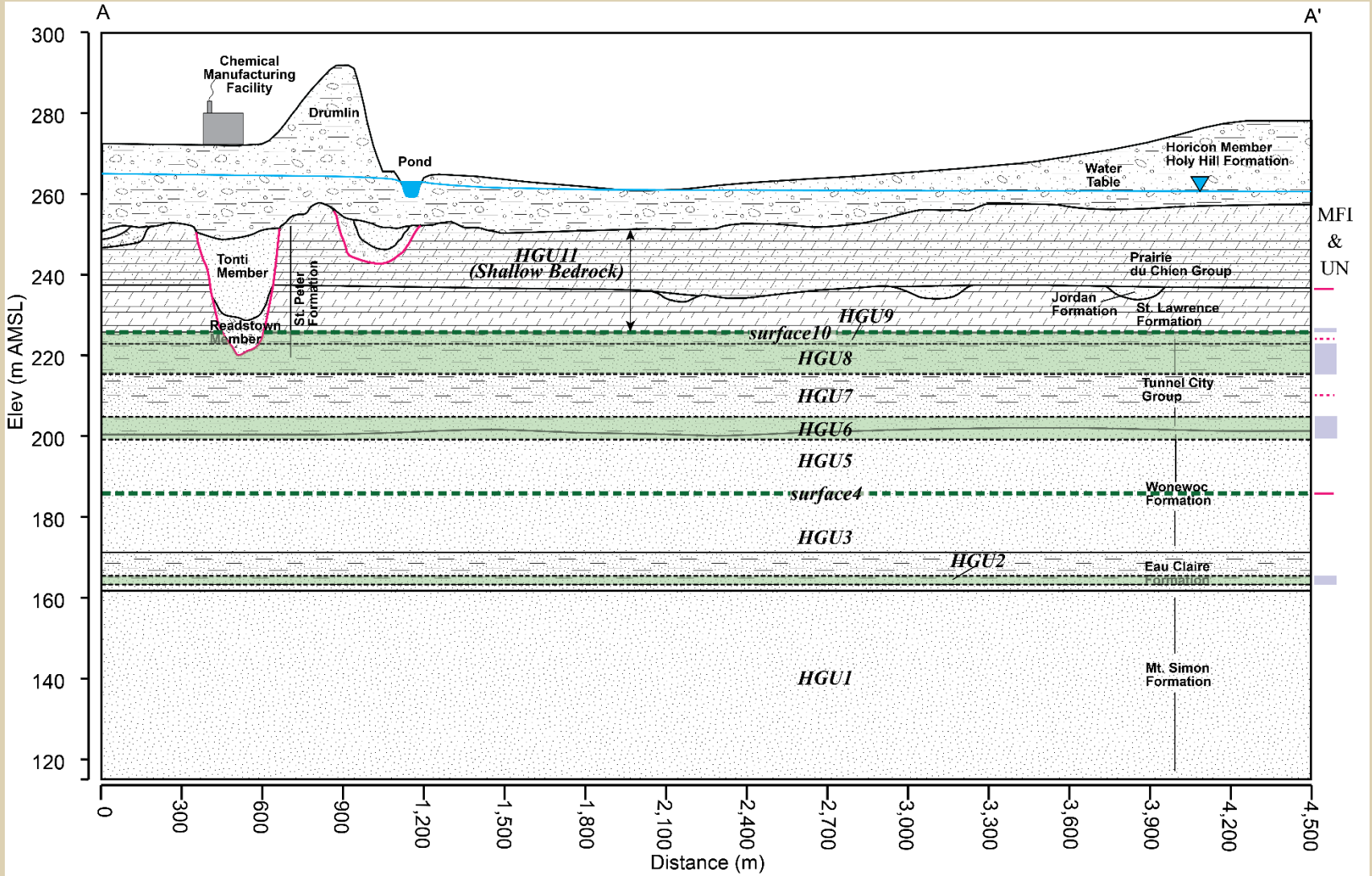


Meyer et al. 2016, JOH


Wisconsin
Fractured Rock Research Site
N
DNAPL
Source Area
Plume ~ 2.8 km
long in 2003
Koshkonong Creek
Flow
Approximate Extent of Observed DNAPL
2003 L5 Plume 10 ppb TVOC Contour
0
500
1,000
2,000
Meters
Research Wells
UW/UG Multilevel Wells
Preexisting Monitoring Network
Barrier System Wells
Multilevel Wells
DNAPL Recovery Wells
Monitoring and Other Wells
Staff Gauges
Village Wells
Other Features
Creeks and Drainage Ditches
3.05 m (10 ft) Elev. Contours


Elev (m AMSL)
MP-6
MP-19S/D
MP-15
MP-21S/D
MP-18
Litho Strat
Lithostrat
Vert Grad
-0.5 m/m 0.5
Class
265
260
255
250
245
240
235
230
225
220
215
210
205
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
Horicon Mbr.
Prairie du Chien Grp.
St. Law. Fm.
Tunnel City Grp.
Wonewoc Fm.
Eau Claire Fm.
Mt. Simon Fm.
Low K_v surface
Aquitard
Aquitard
Aquitard
Low K_v surface
Aquitard
Meyer et al. 2016, JOH
A (west)
flow
4 km
flow
A' (east)

Head Profiling Technique Delineates Multiple Aquitards



Aquitard unit

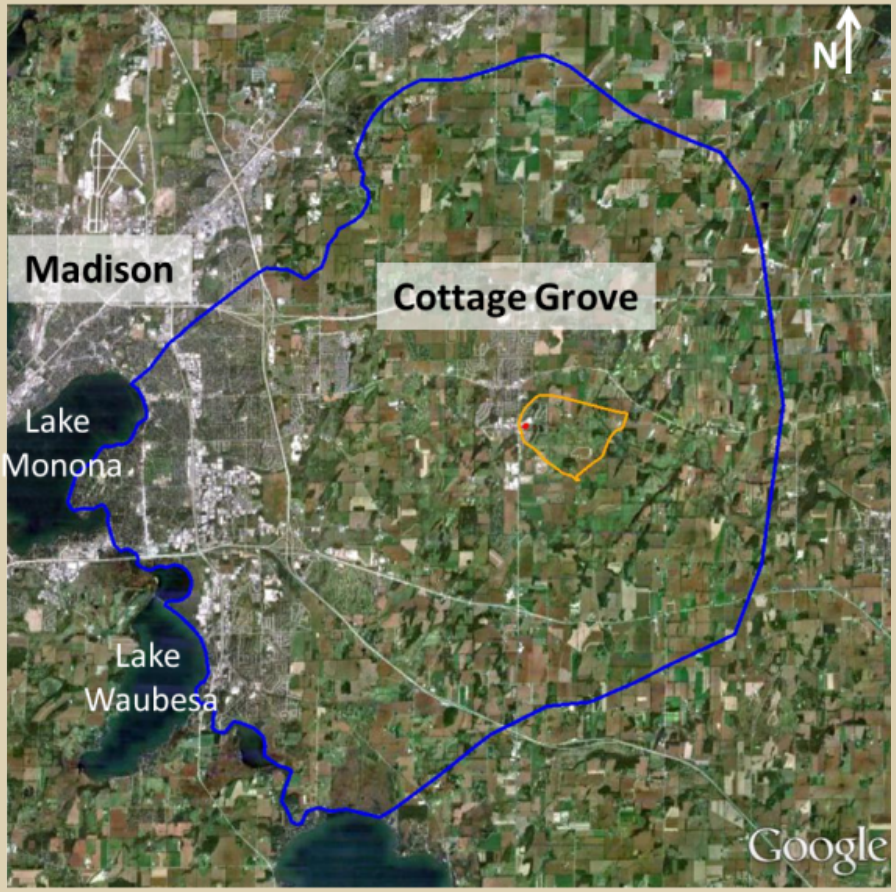
Poor vertical connectivity across surface

Meyer et al., 2023, in submission

Aquitard Integrity Metrics

1. Thickness
2. Continuity
3. Bulk K_v
4. Integrity with respect to DNAPL
5. Integrity with respect to dissolved phase contaminants

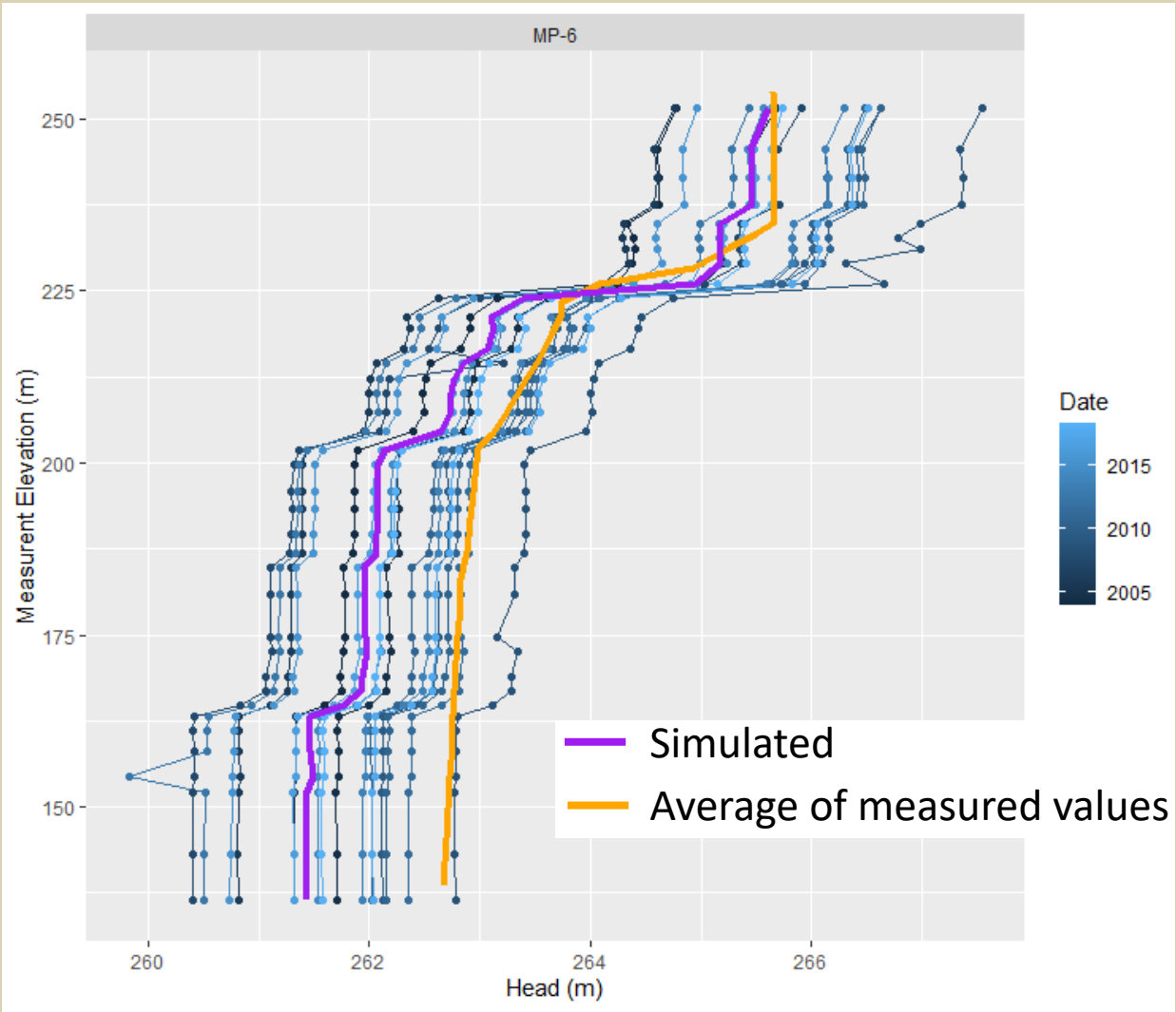
Estimating K_v Using a 3-D Groundwater Flow Model Calibrated with Head Profiles



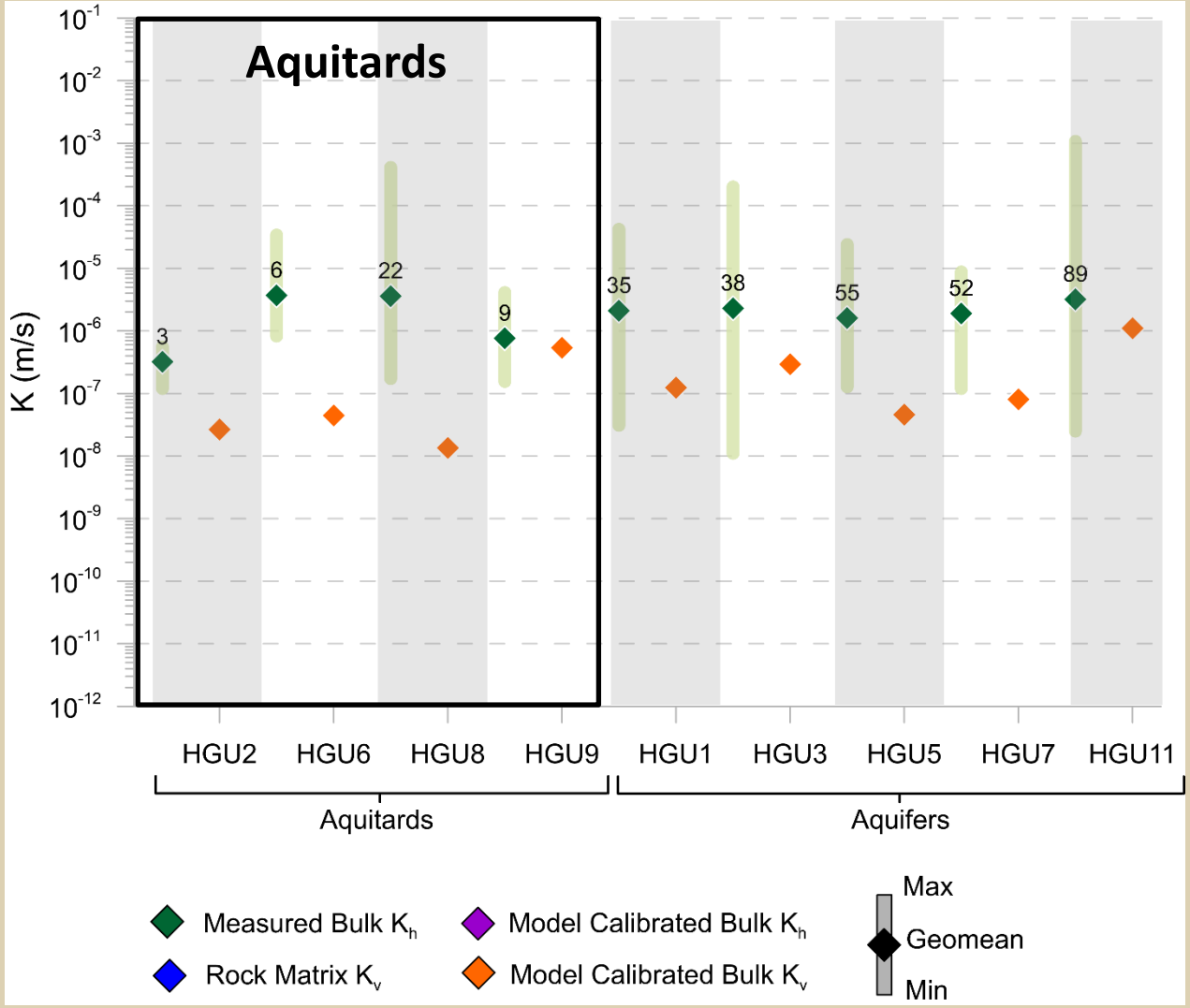
DNAPL source zone

Max extent dissolved phase plume

Flow model domain



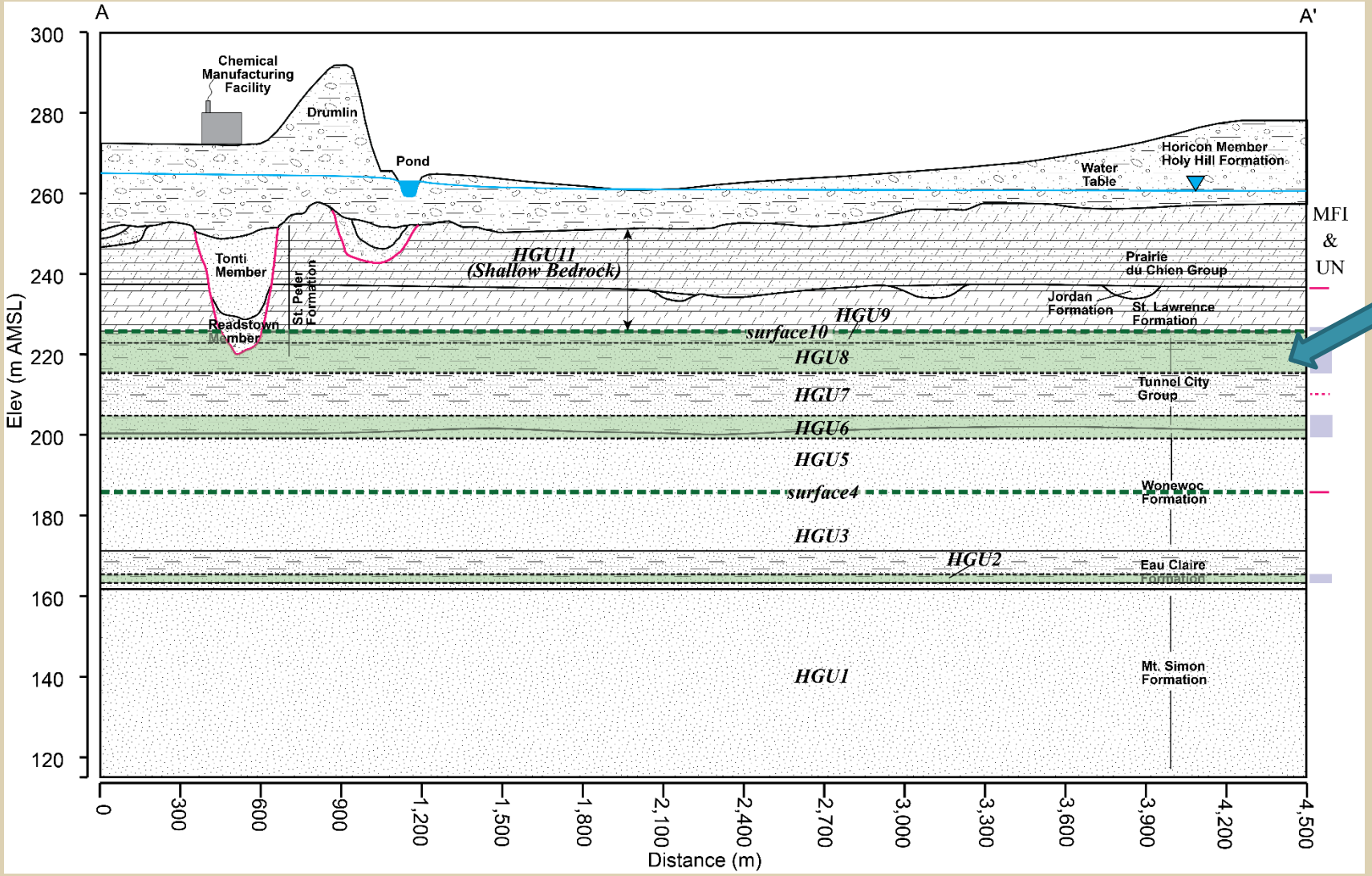
K Data Indicates Substantial Anisotropy for Most Aquitards



- HGU8 (Upper Tunnel City Grp. aquitard) has the lowest K_v
- K_v are generally 1-3 o.m. lower than K_h for each aquitard
- **Aquitardifers !!!**

Meyer et al., 2023, in submission

K Data Indicates HGU8 is the Highest Integrity Aquitard

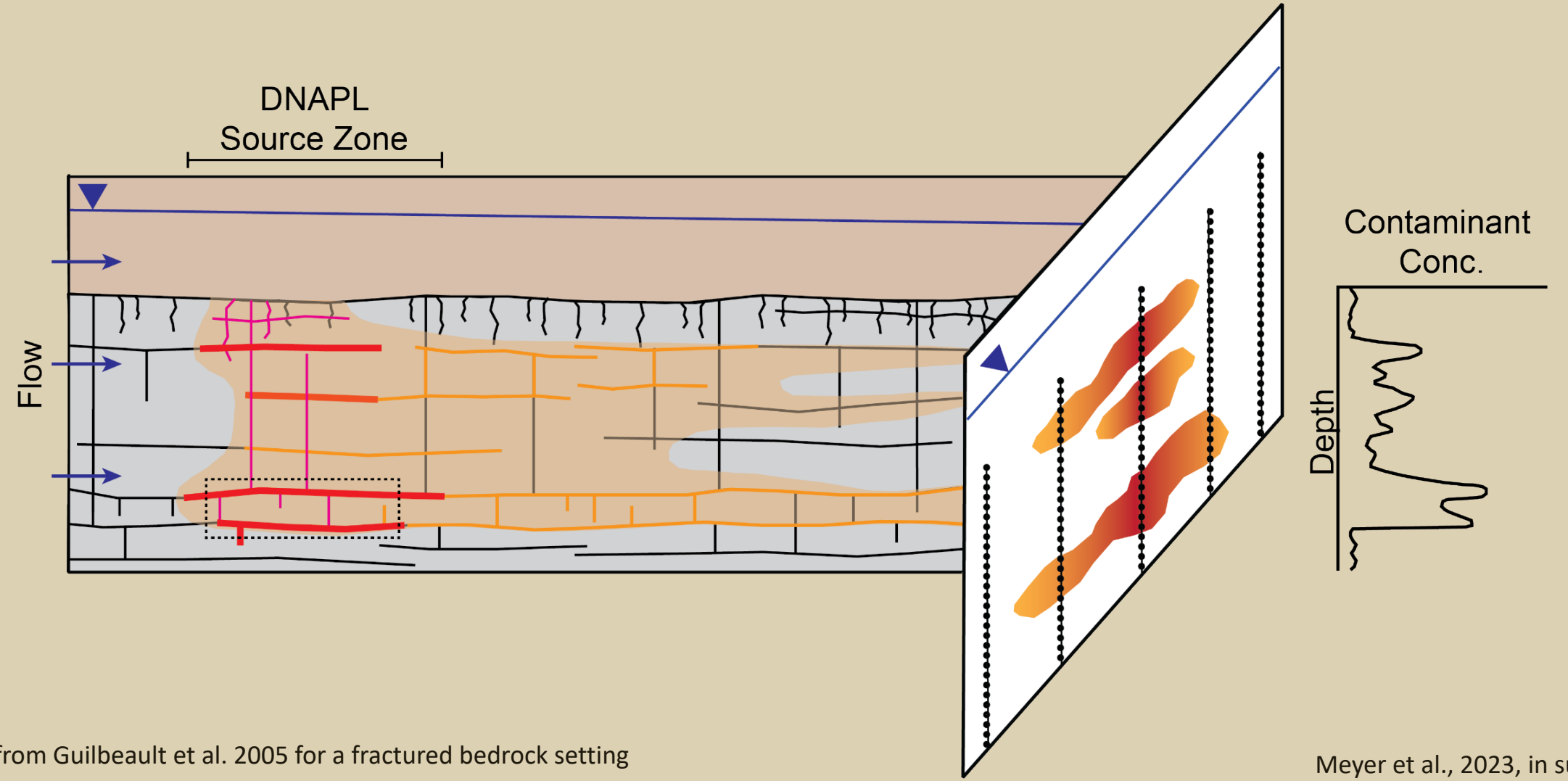


Meyer et al., 2023, in submission

Research Question

Where did DNAPL accumulate within the bedrock and is it consistent with the aquitards delineated based on head profiles?

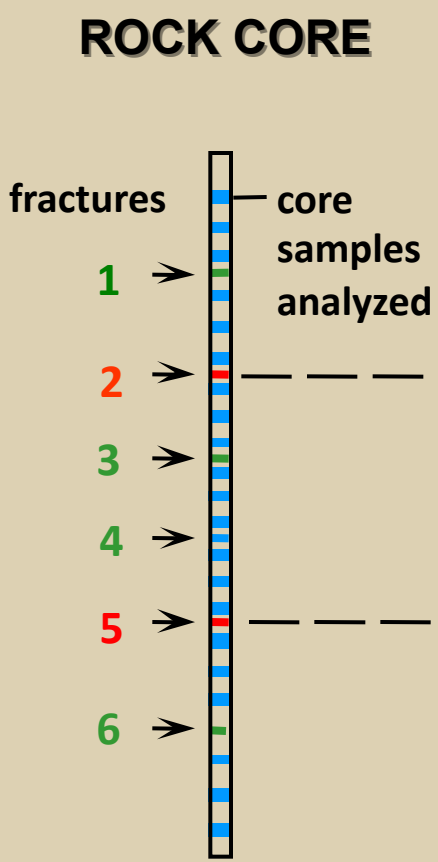
Approach

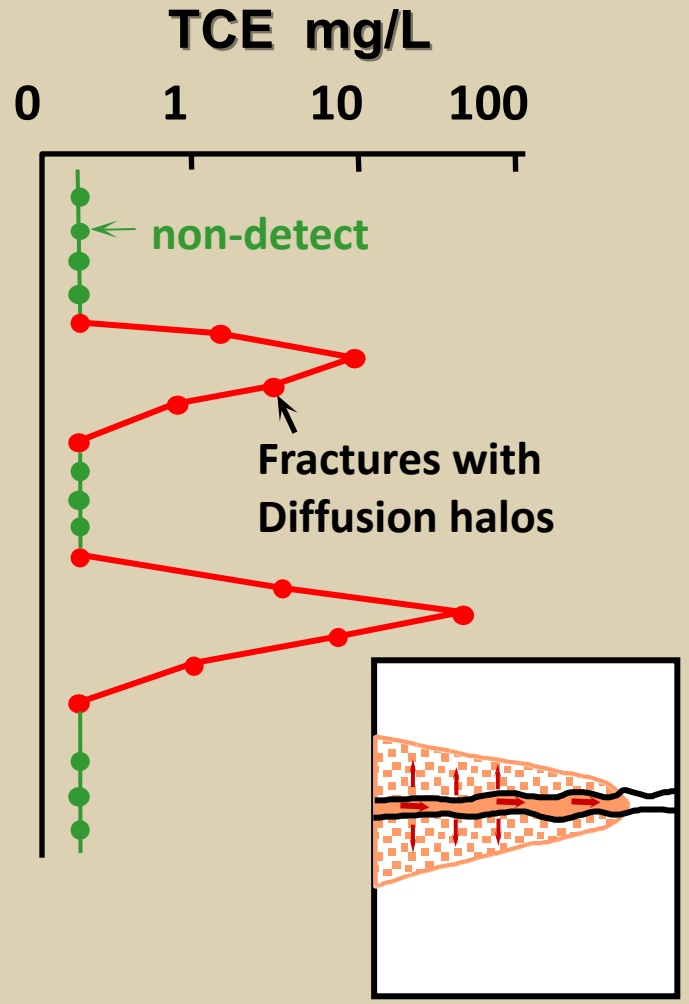


Modified from Guilbeault et al. 2005 for a fractured bedrock setting

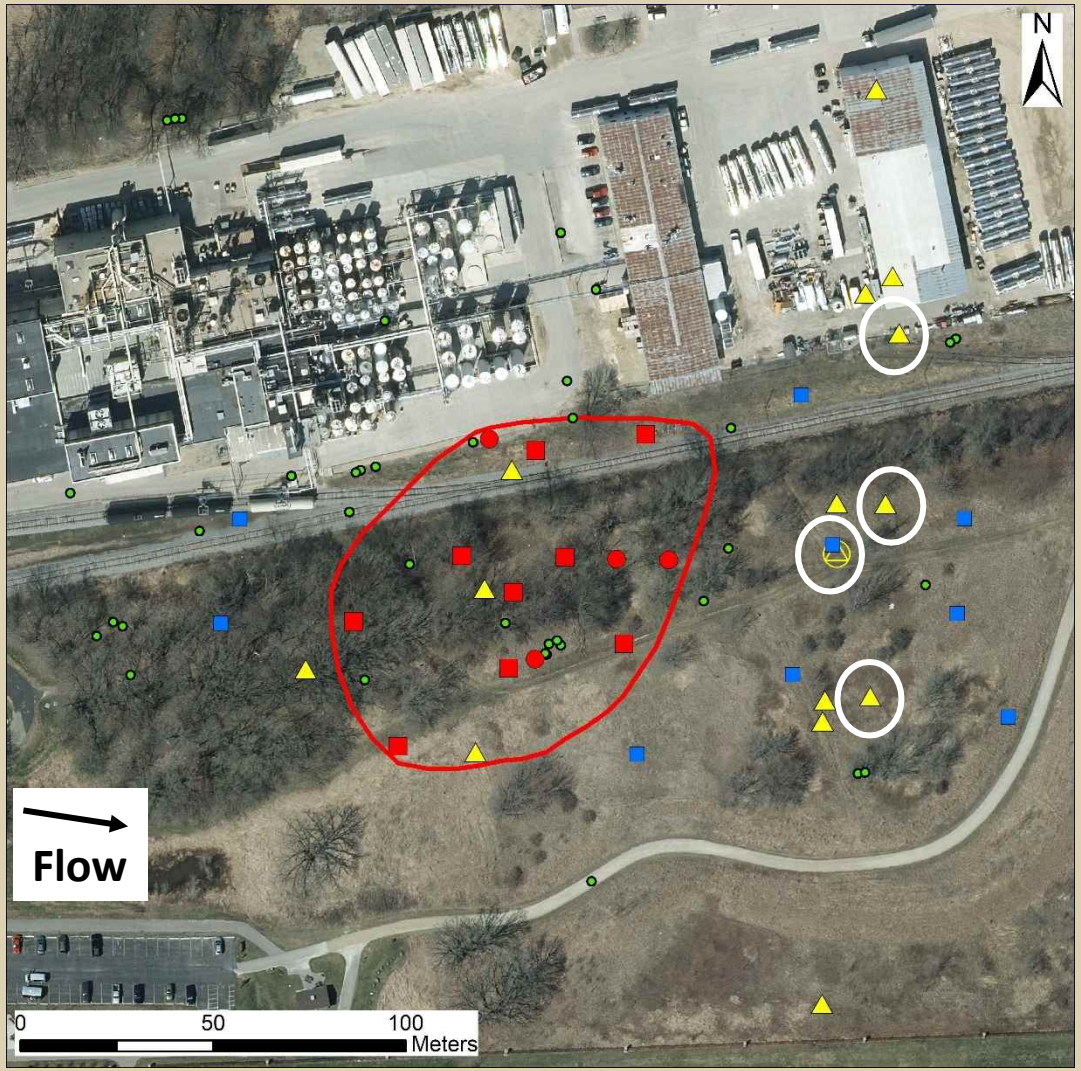
Meyer et al., 2023, in submission

Core Sampling for Vertical Contaminant Distribution





Source Zone Data Collection

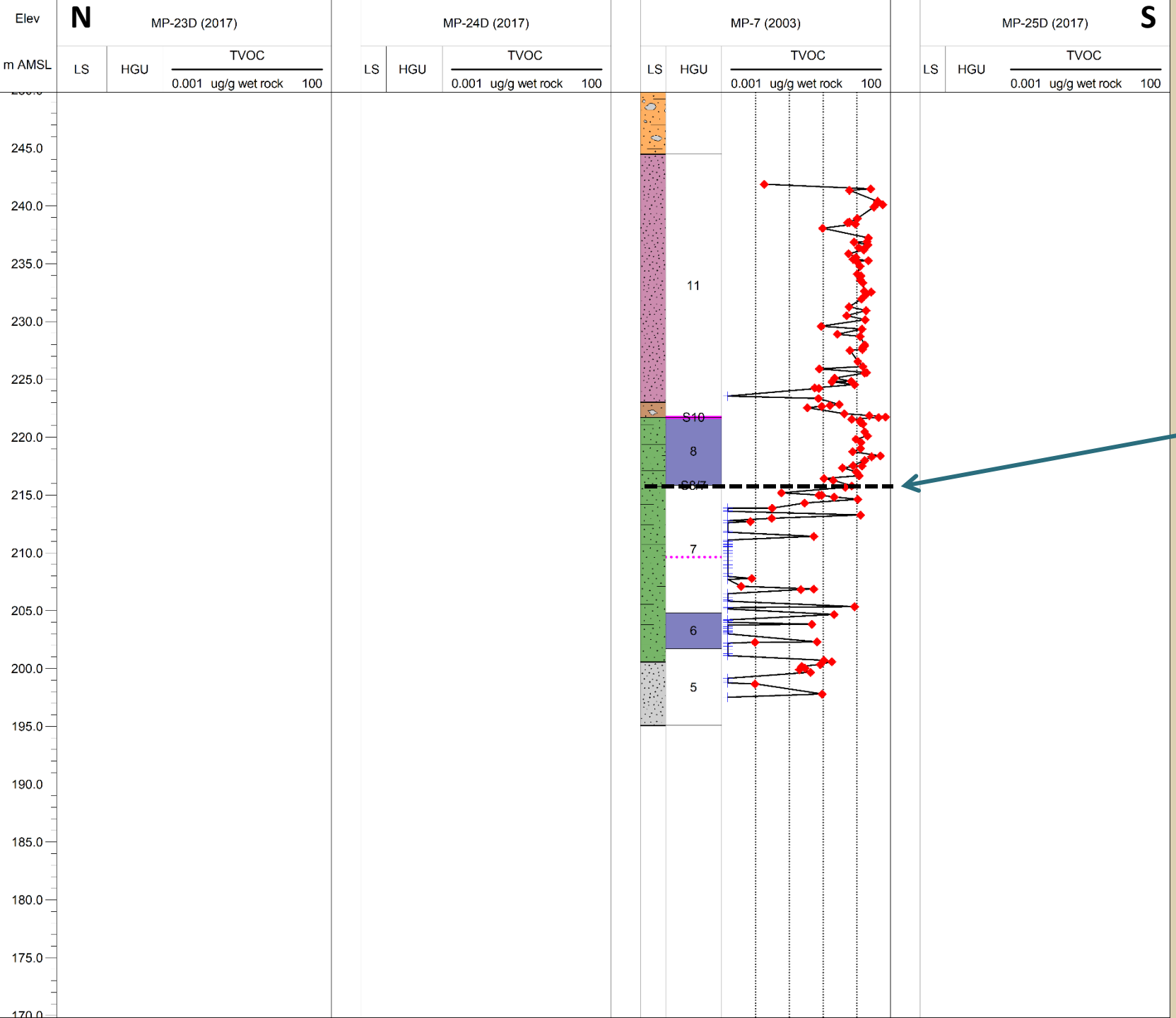


High Resolution Research Stations

- Current
- Abandoned

Conventional Wells

- No pumpable DNAPL
- Pumpable DNAPL
- Other monitoring well

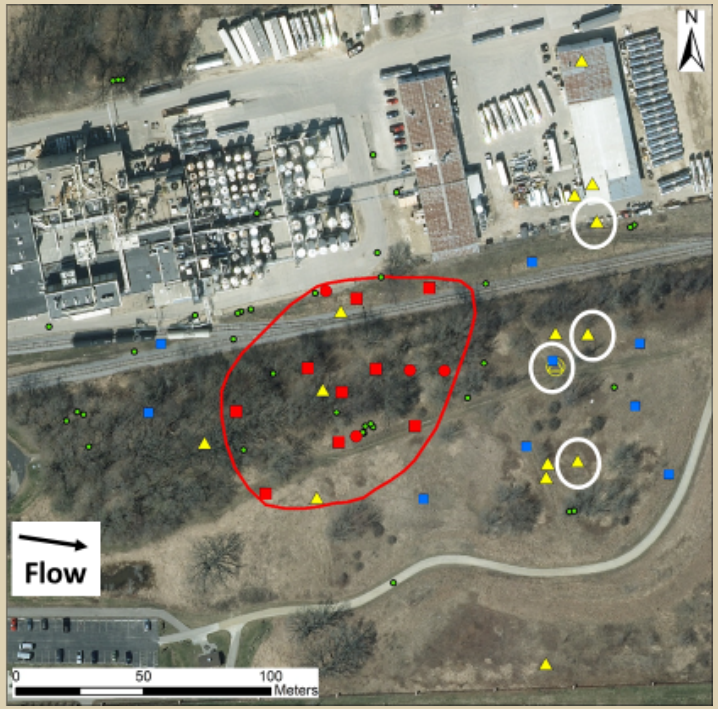


Rock Contaminant Profiles

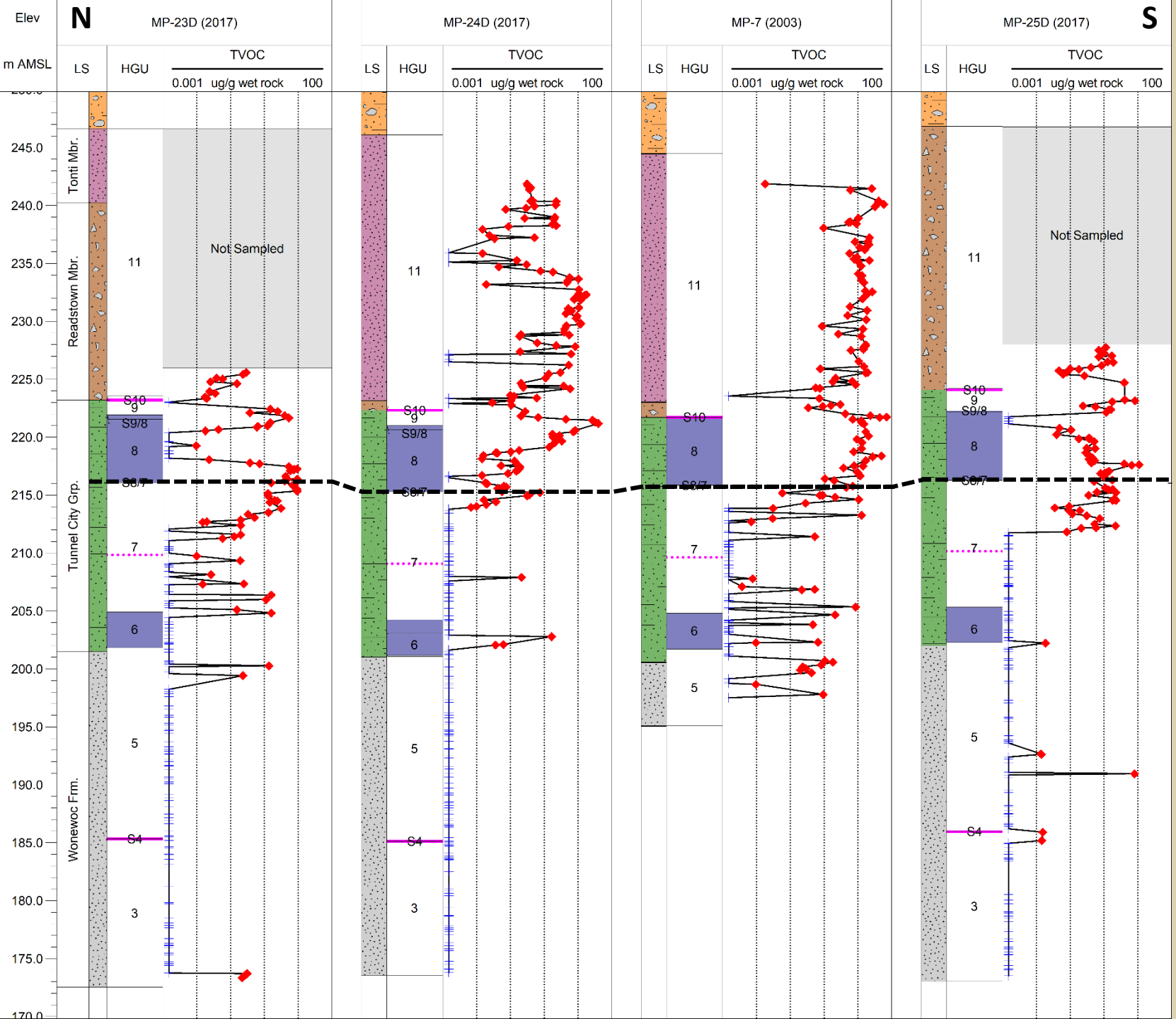
Quantifiable

\+ Non-Detect

Max extent of observed DNAPL



Meyer et al., 2023, in submission



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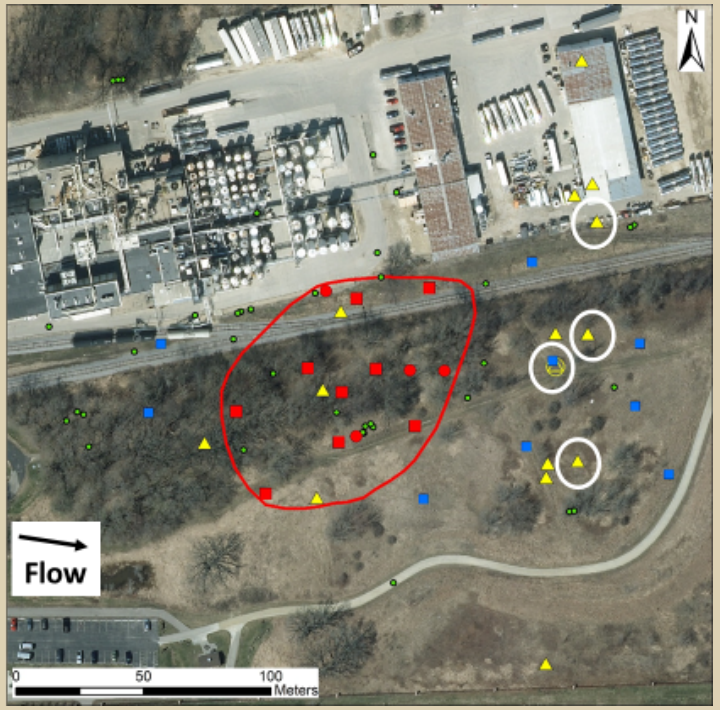
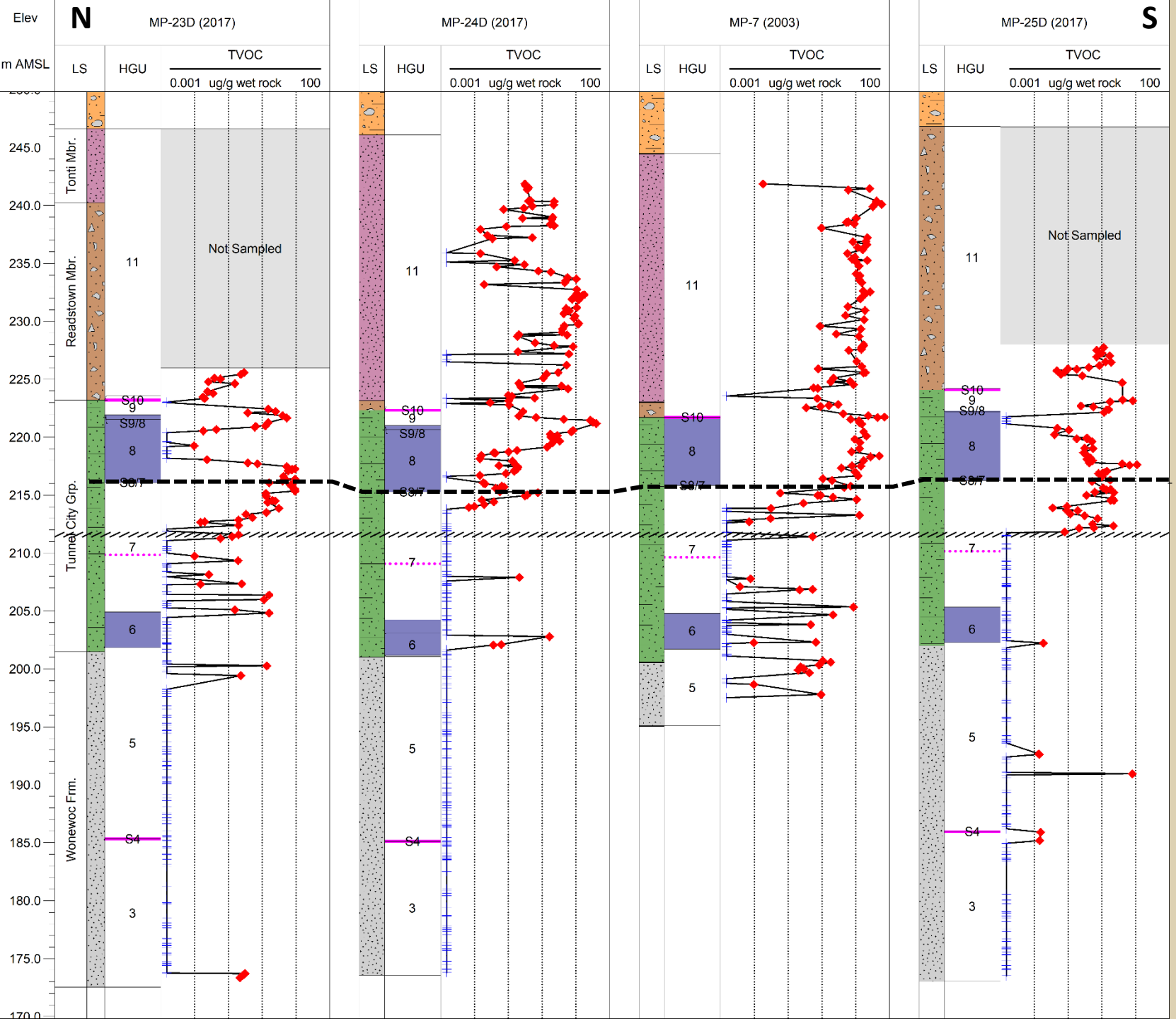
Max extent of observed DNAPL



Meyer et al., 2023, in submission

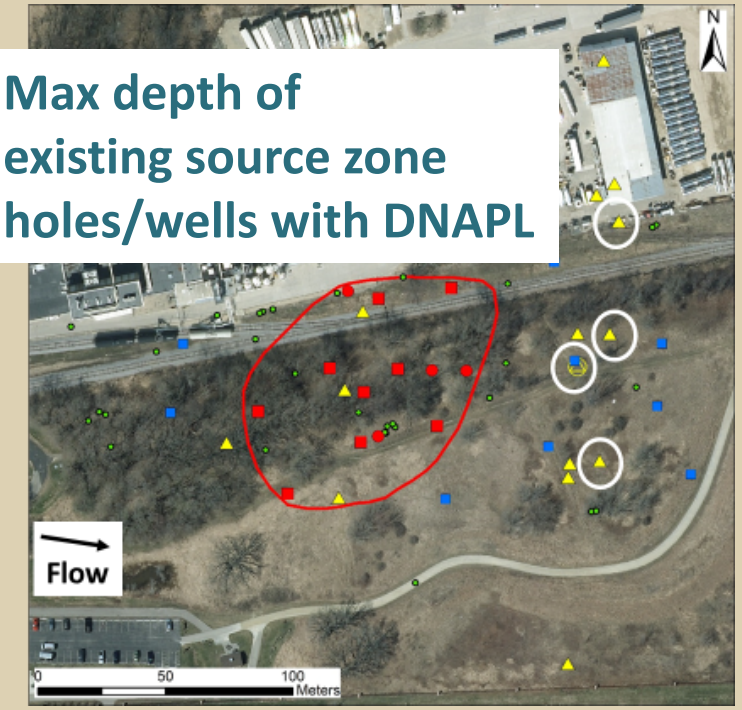


Rock Contaminant Profiles

- Quantifiable
- \+ Non-Detect

Max extent of observed DNAPL

Max depth of existing source zone holes/wells with DNAPL

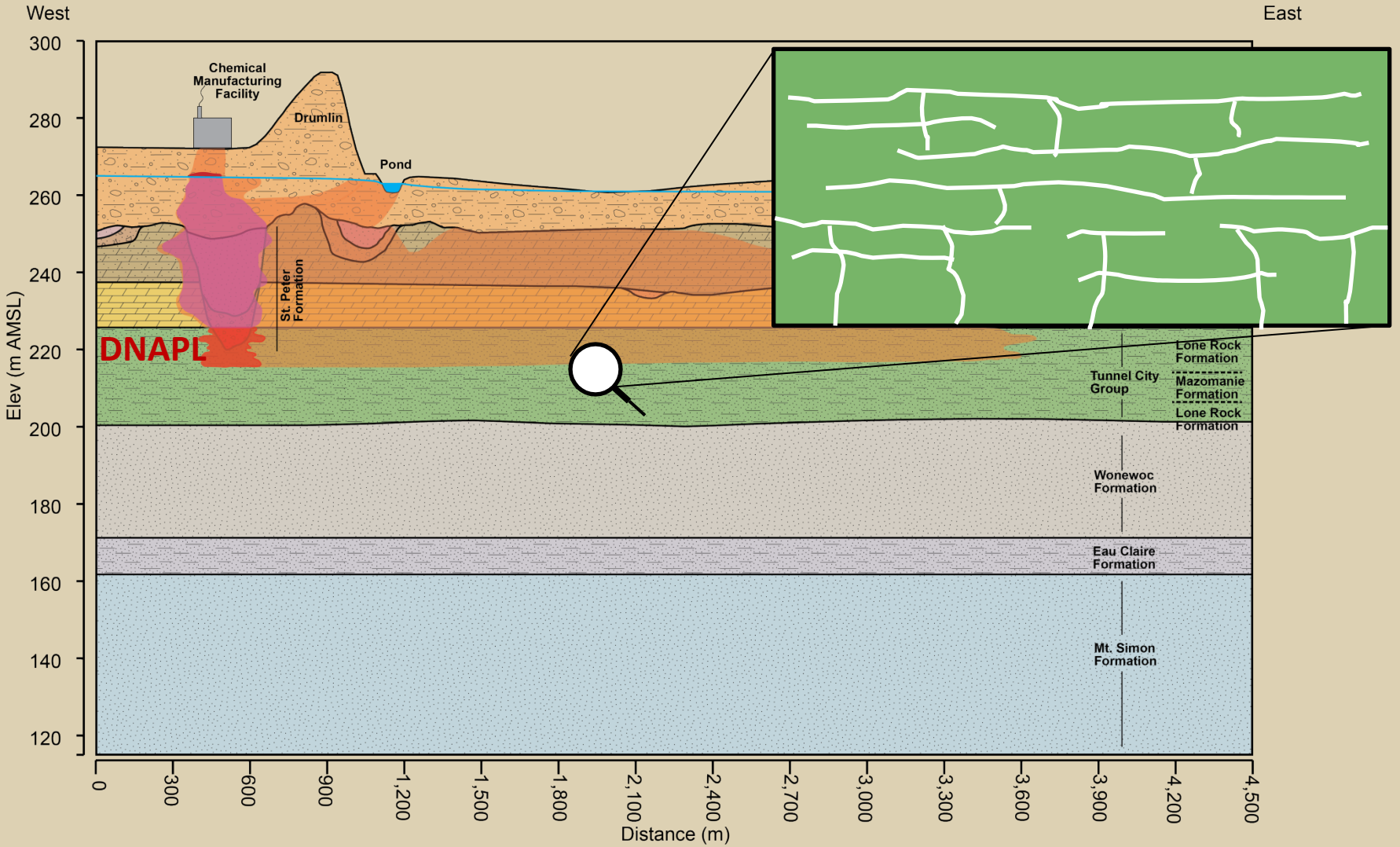


Meyer et al., 2023, in submission

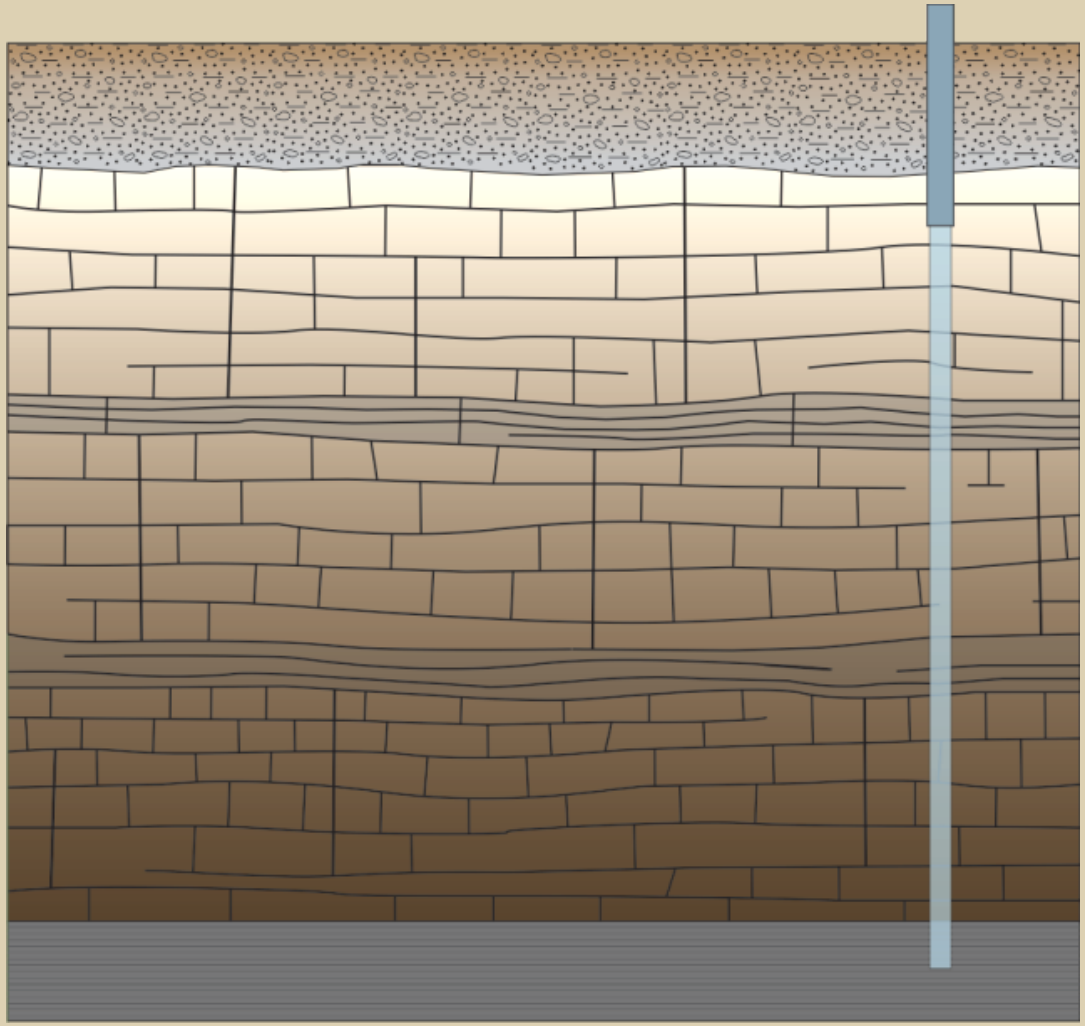
Key Points

- Contaminant concentration profiles do not indicate any important aquitards, accumulation zones, above the HGU8 aquitard
- The DNAPL did not accumulate on top of the HGU8 aquitard
- The DNAPL accumulated in and migrated to the bottom of the HGU8 aquitard but did not migrate into the underlying aquifer

What are the Characteristics of the Secondary Porosity Features?

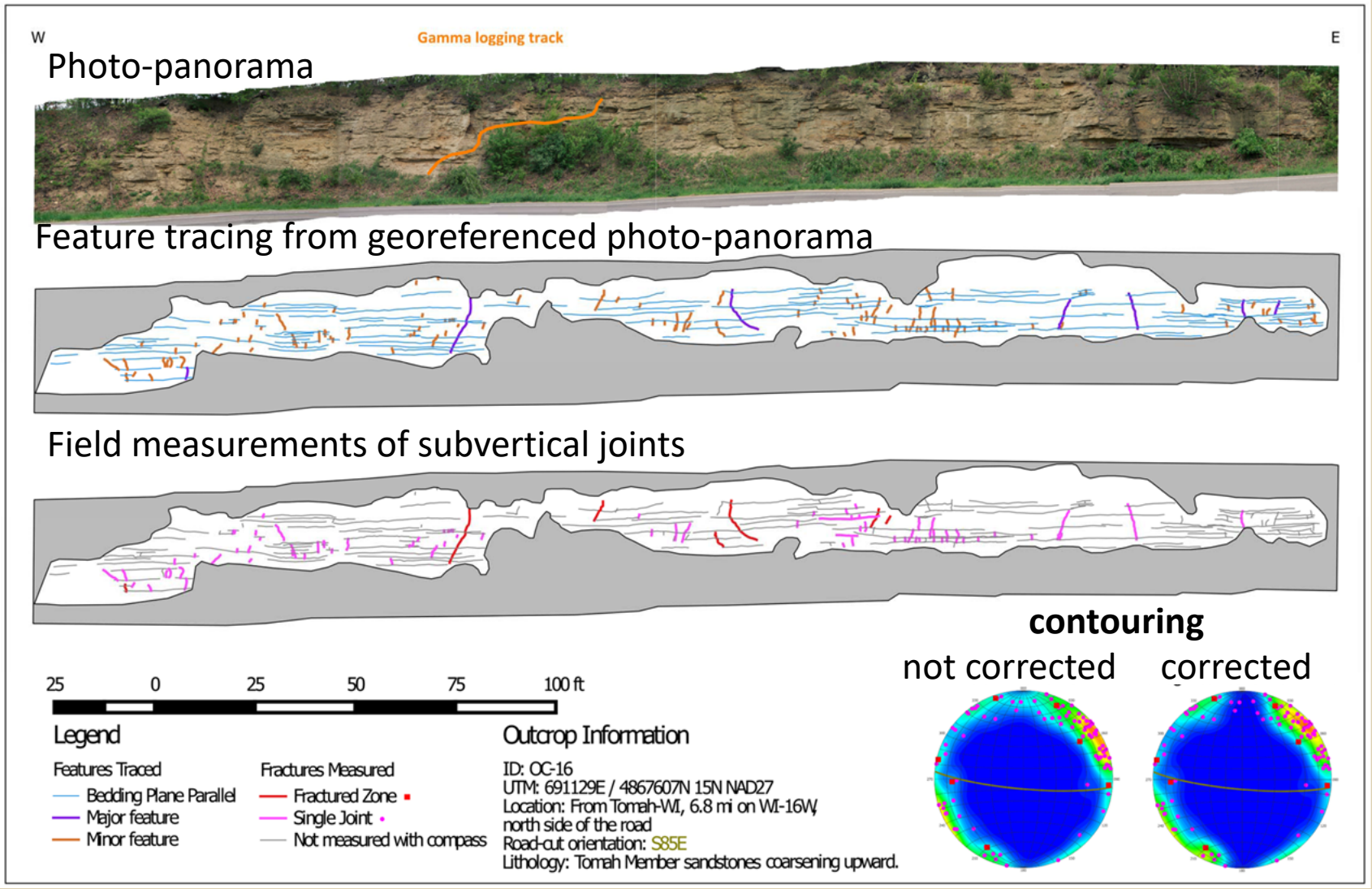


Vertical Boreholes Underrepresent Vertical Fractures



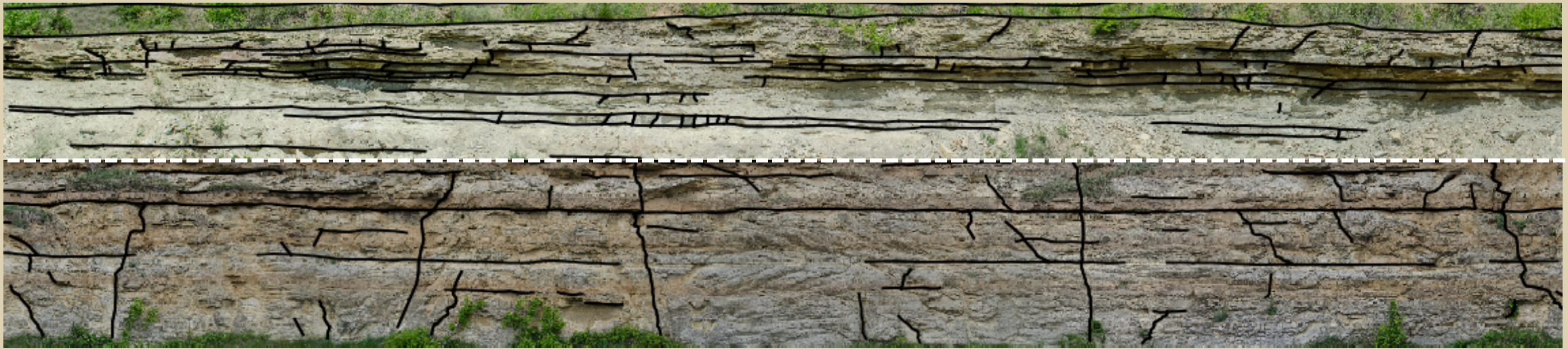
from Munn (2012)

Outcrop Fracture Characterization Approach



Ribeiro, MASc, 2016

Fracture Network Contrasts in Tunnel City Group



HGU8
Aquitard

HGU7
Aquifer

Ribeiro, MASc, 2016

Mechanical Interface Restricts Vertical Flow

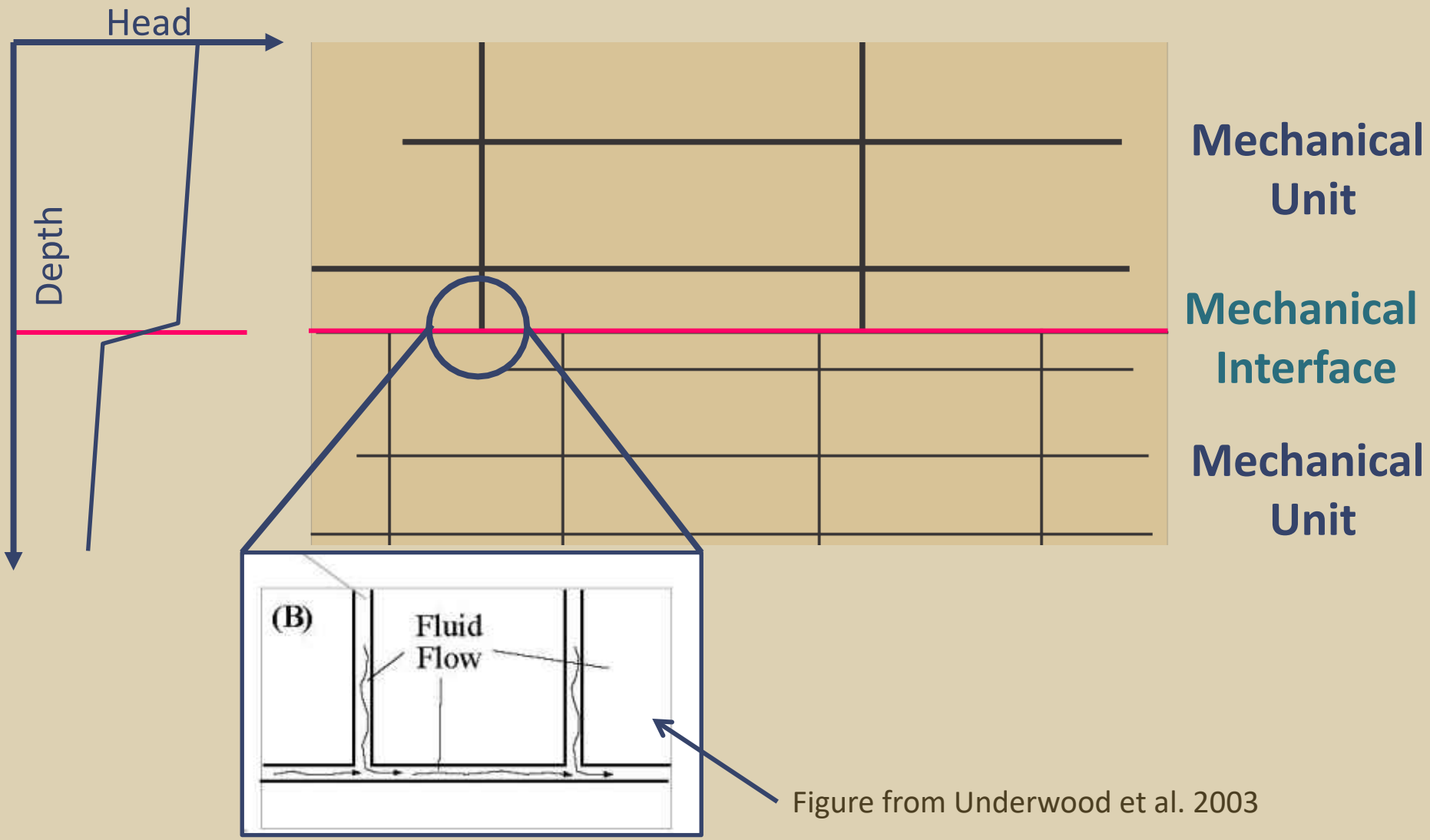
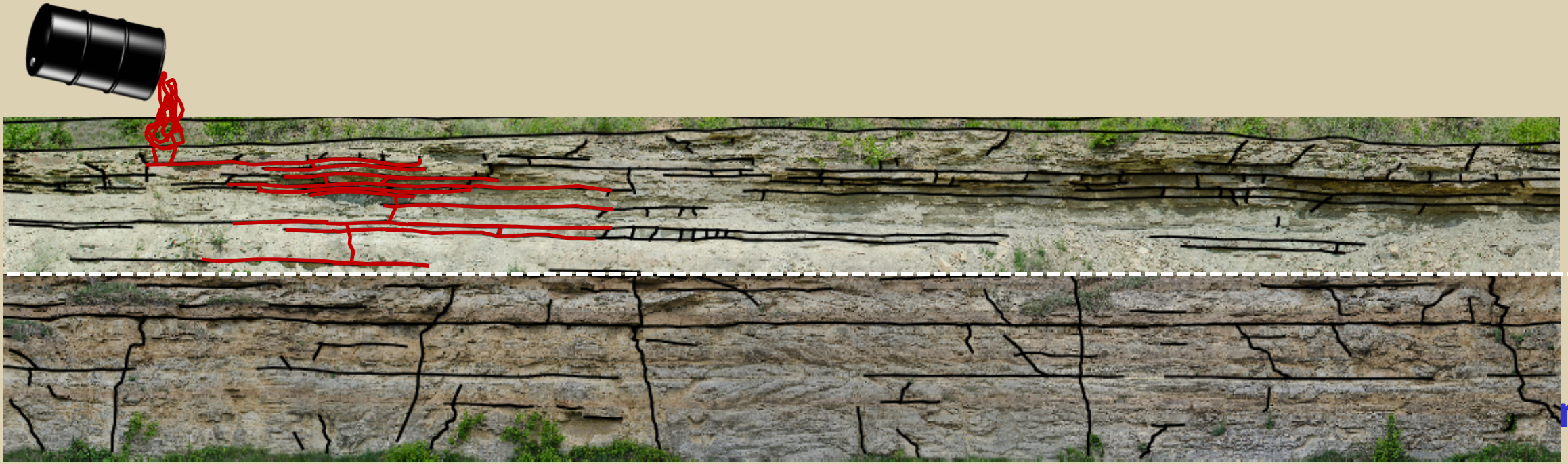


Figure from Underwood et al. 2003

Fracture Network Contrasts in Tunnel City Group



HGU8
Aquitard
DNAPL

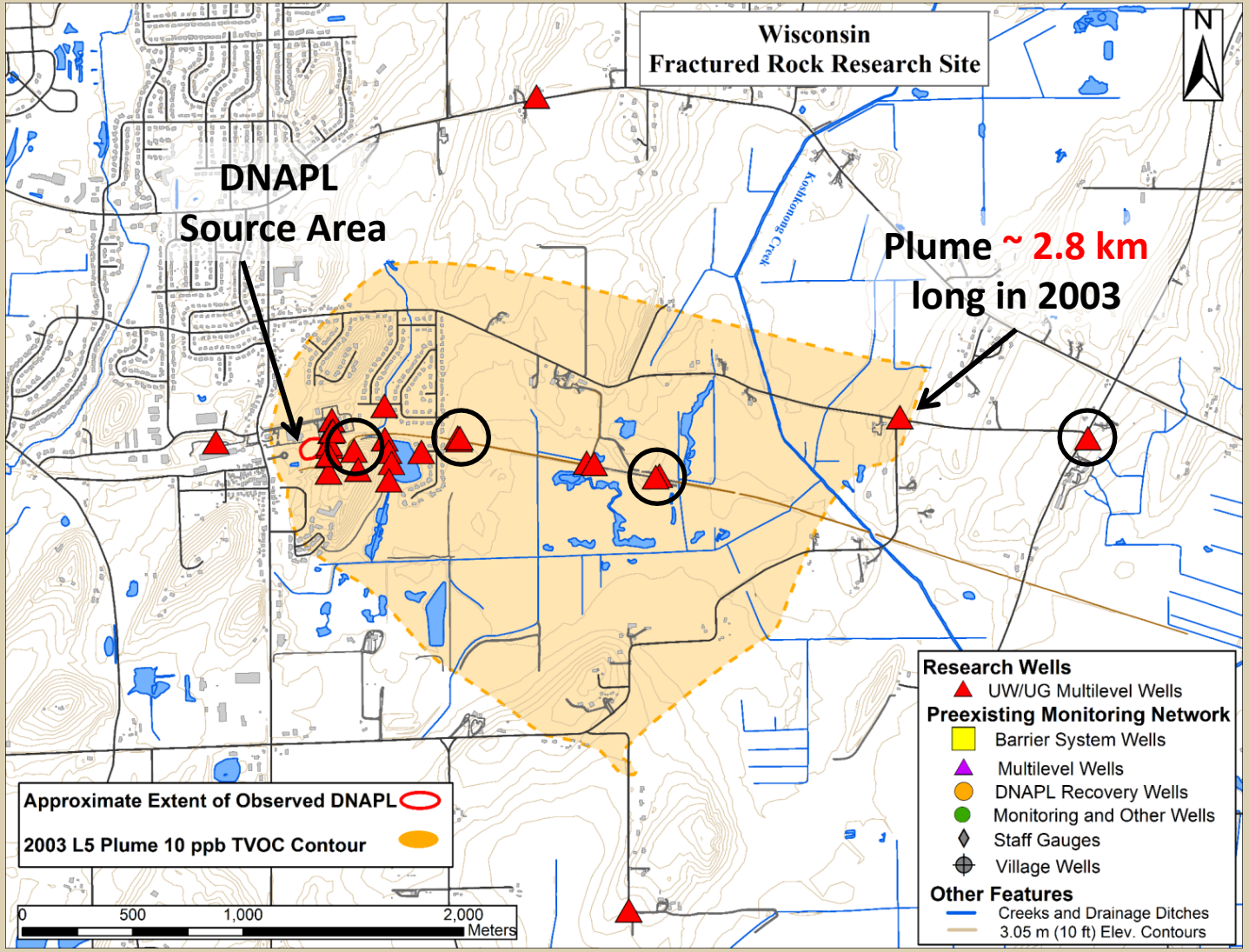
HGU7
Aquifer
no to minimal DNAPL

Ribeiro, MASc, 2016

Key Point

Mechanical interfaces can serve as important aquitards by stopping the downward migration of DNAPL

Plume is 3 Kilometers Long



Groundwater Contaminant Profiles

E

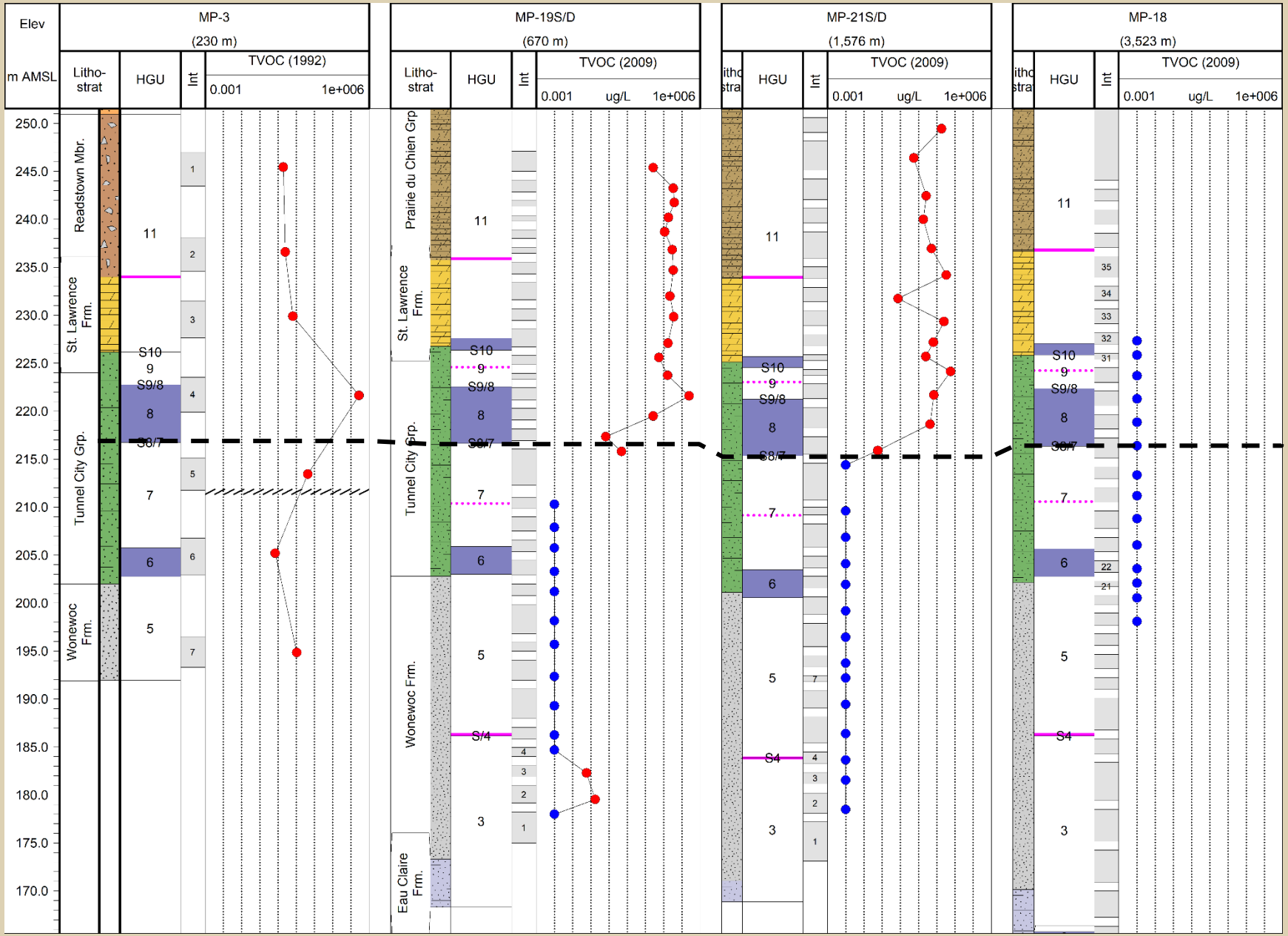
Source

Mid-Plume

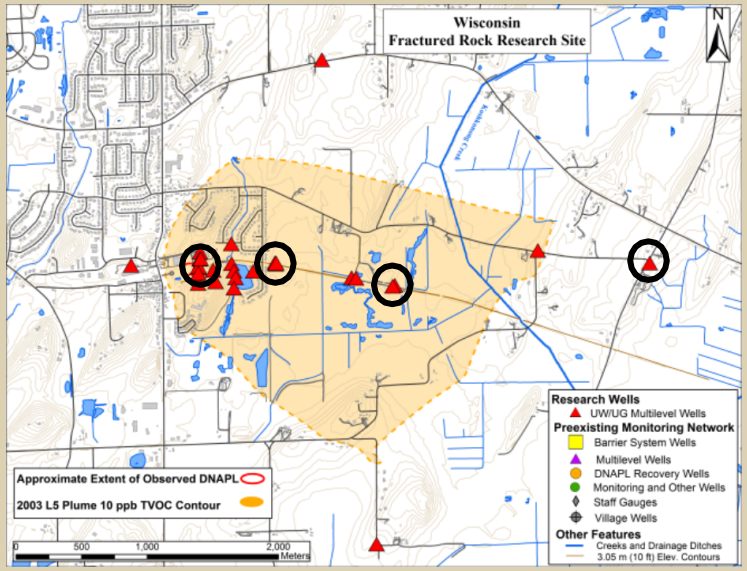
Plume Front

Outside of Plume

W



- Quantifiable
- \+ Non-Detect

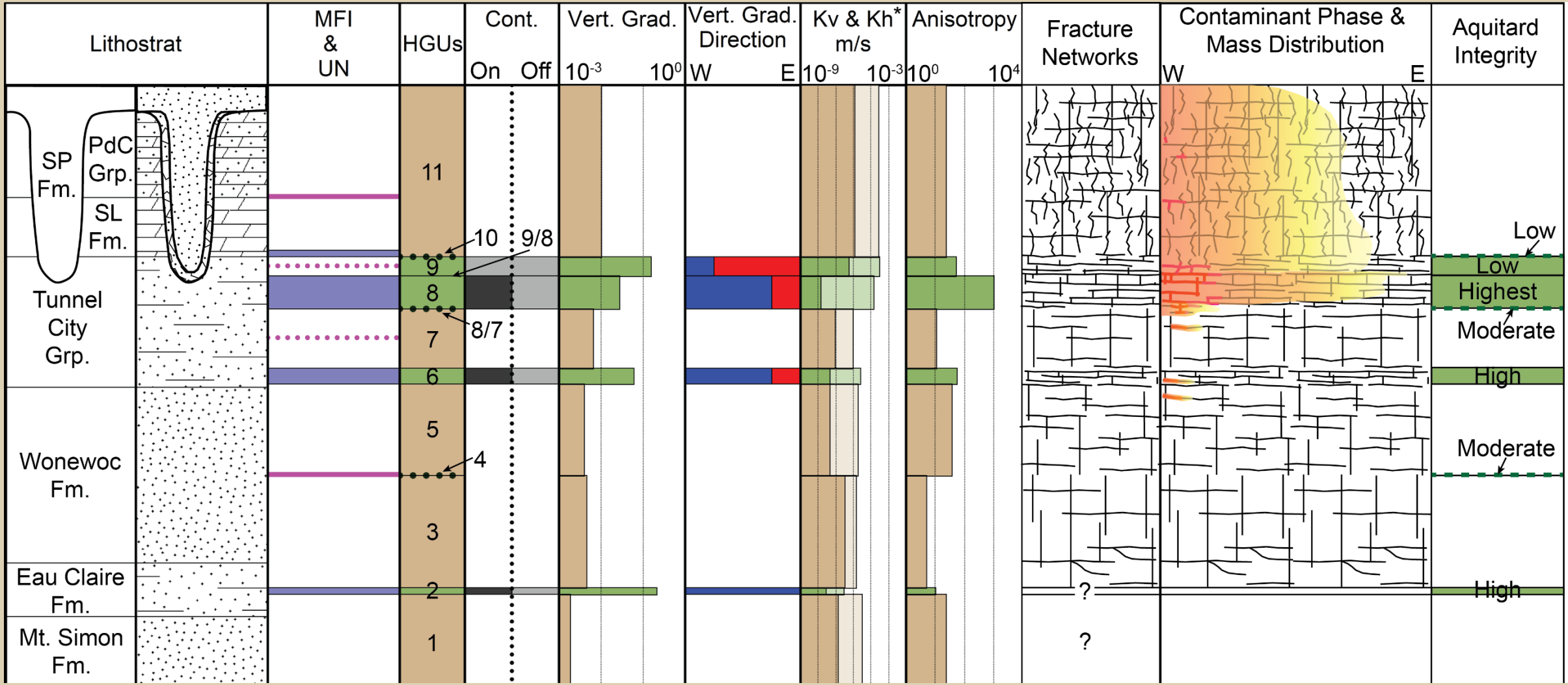


Meyer et al., 2023, in submission

Key Point

Lateral transport of contaminants in an anisotropic aquitard prevents vertical spreading of the plume as it migrates downgradient

Multiple High Integrity Aquitards



Meyer et al., 2023, in submission

Key Insights into Shallow, Fractured Sedimentary Rock Aquitards

- Thin units with moderate K_v and surfaces representing poor vertical connectivity can be high integrity aquitards with respect to DNAPL
- Anisotropy can enhance the integrity of aquitards with respect to the DNAPL and dissolved phases
- Long screened wells and other conventional methods are likely to miss important aquitards in shallow, fractured sedimentary rock

Questions?

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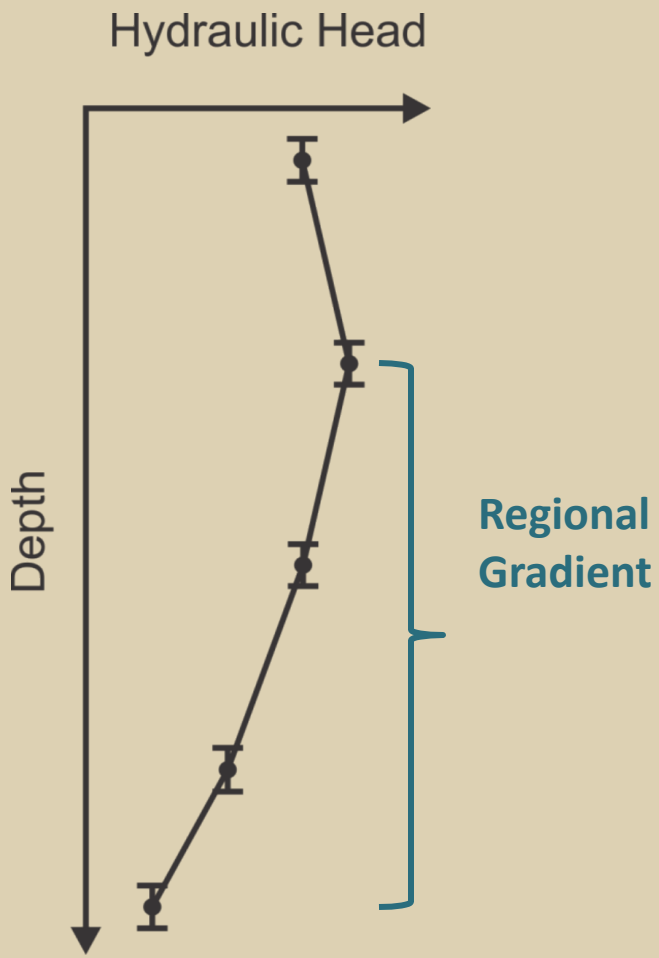
@HawkeyeHydrogeo

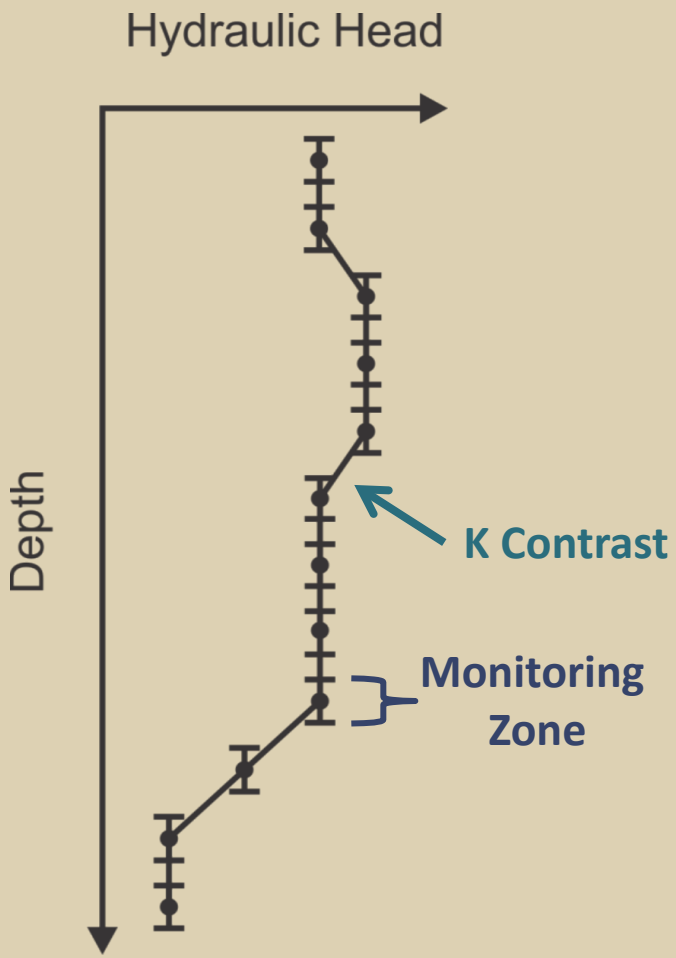
Extras

Why High Resolution?

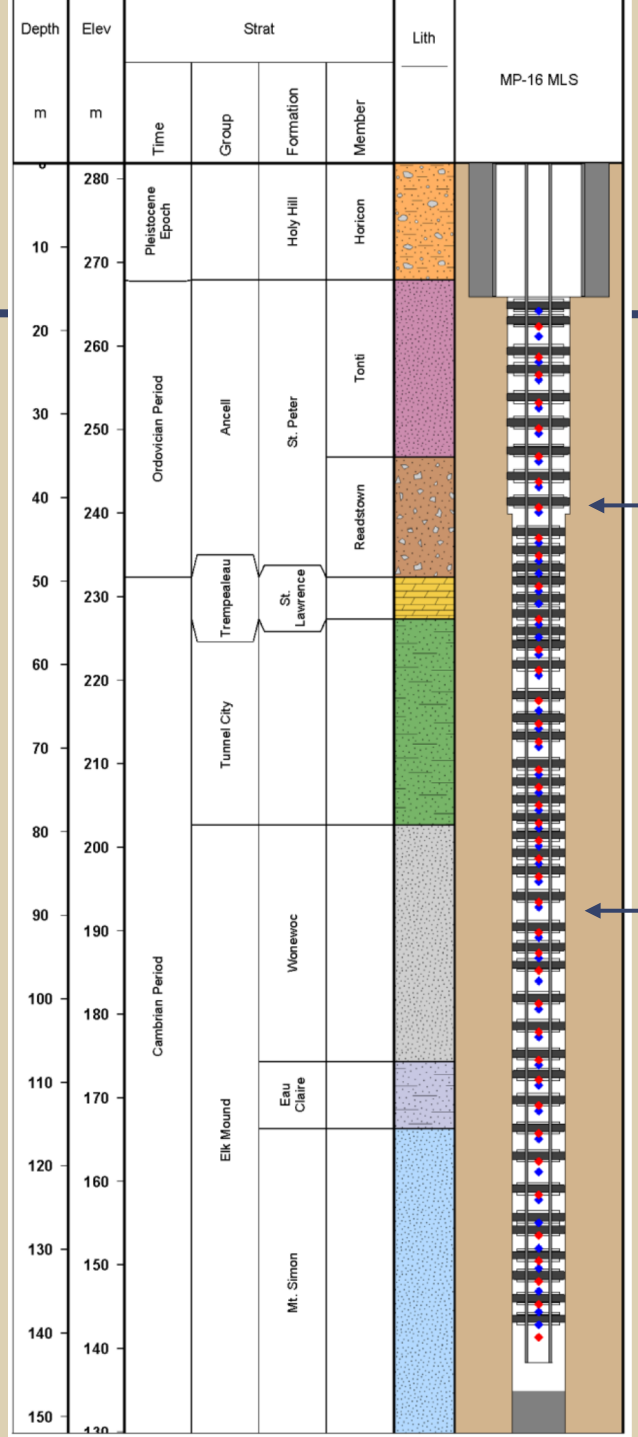
Sparse



Numerous



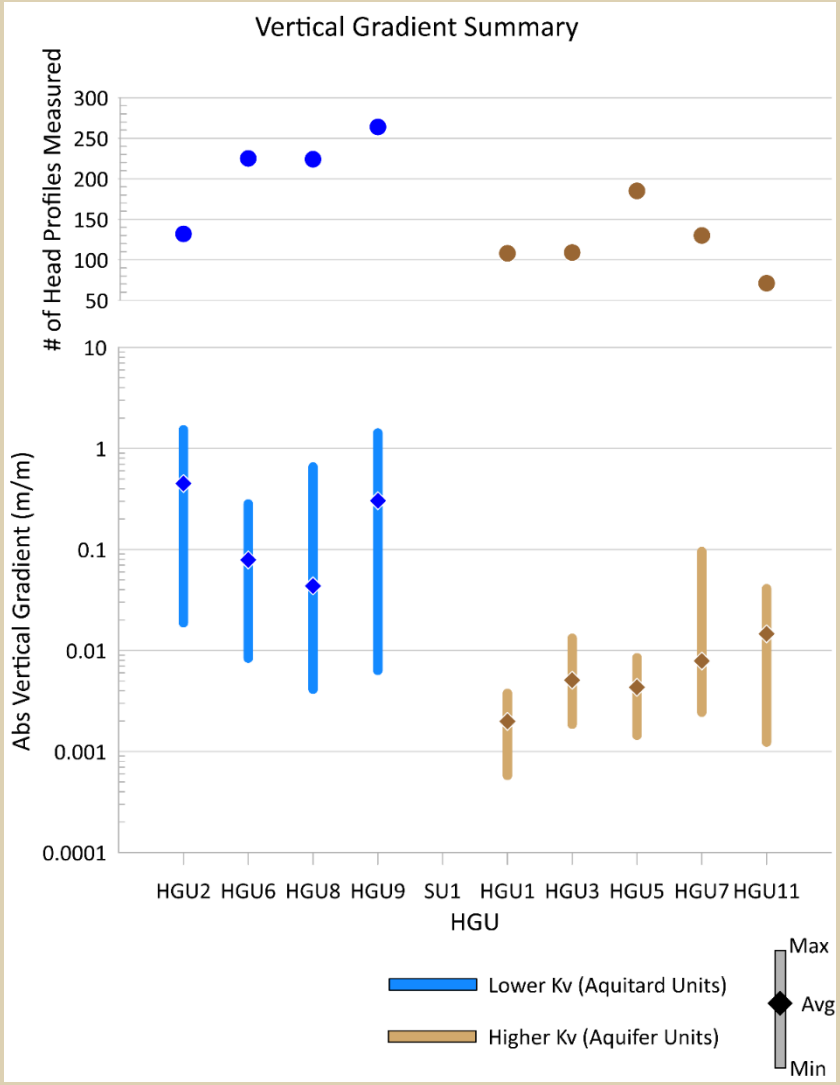
High Resolution Design



Westbay Multilevel System

- ✓monitors 129.5 m of bedrock
- ✓46 monitoring zones
- ✓3.6 zones per 10 m
- ✓32% sealed

Vertical Gradients



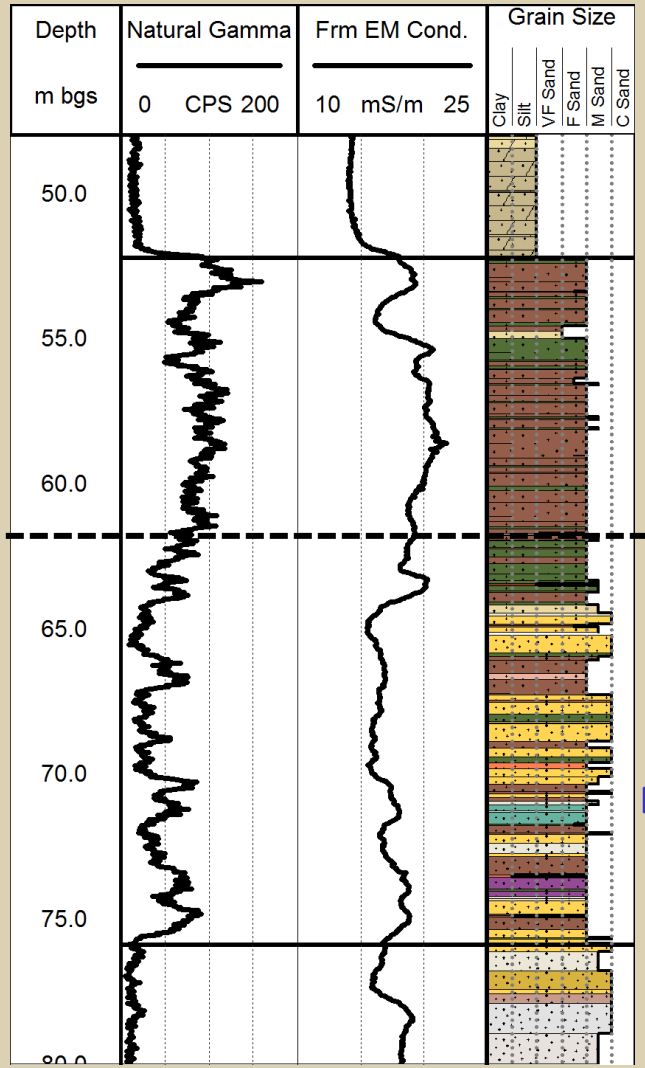
- Vertical gradients in units defined as aquitards are larger than in units defined as aquifers
- The largest vertical gradients are observed across HGU2

Geologic Characteristics of the Upper Tunnel City Group Sandstones

Tunnel City Group

HGU8 Aquitard

HGU7 Aquifer



DNAPL

no DNAPL