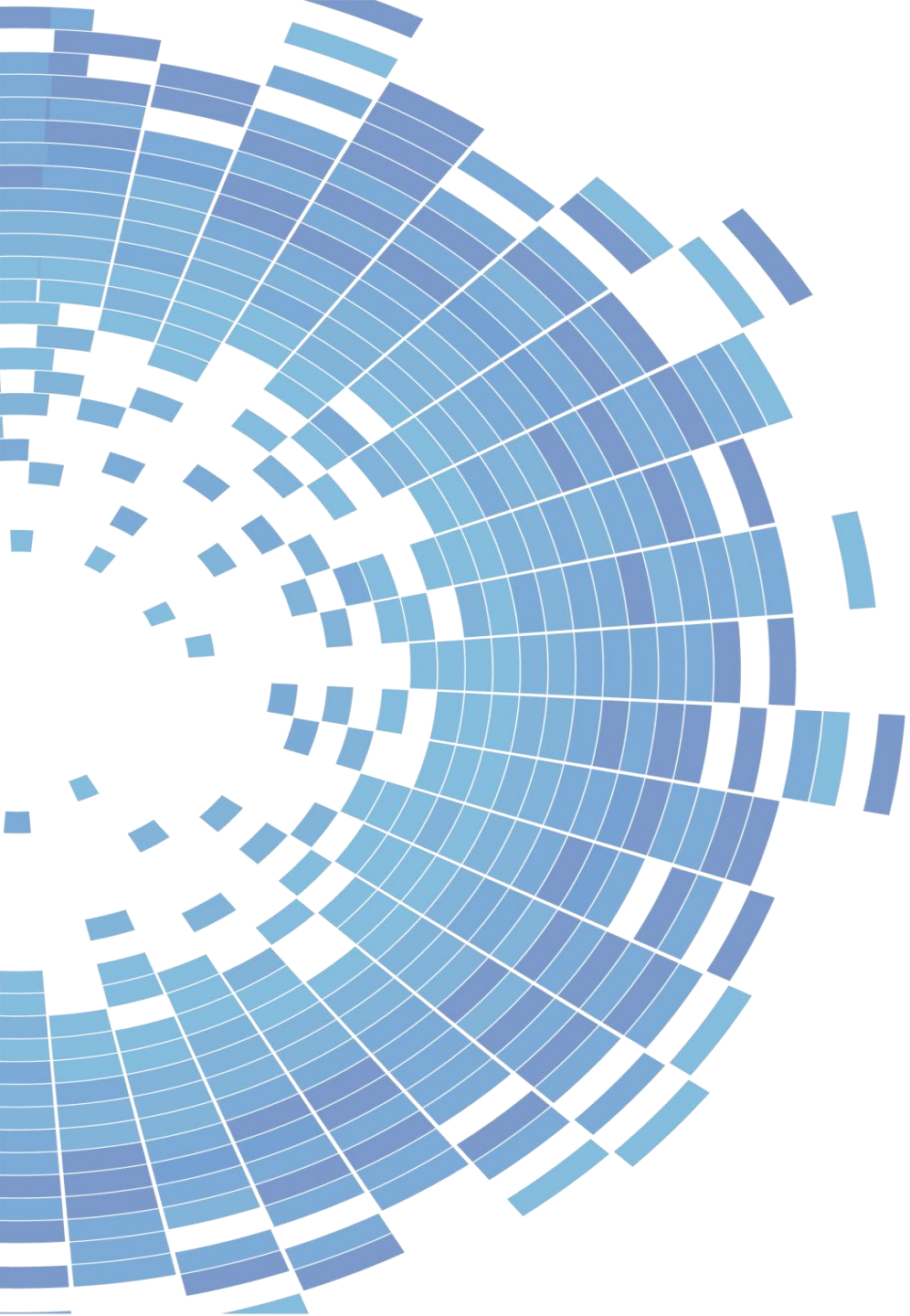

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engineers | scientists | innovators

# DPT Jet Injection of Microscale ZVI for Remediation of Chlorinated Solvents in Clay Till: Results and CSIA after 4 Years of Treatment at Møllevej 9 in Nivå

Chapman Ross
cross@geosyntec.com

ATV Vintermøde - Vingsted
6 March 2019

# Partners in Developing DPT Jet Injection

Region Hovedstaden

FRx

COWI

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# Two Key Take Home Points

## Jet Injection Provides:

### 1) Control delivery of remediation amendments in tough geologic settings:

- Clay, till, saprolite, weathered bedrock

### 2) Competitive costs for treatment:

- \$80-200/$m^3$ for ZVI treatment

# **Problem Statement:** Treat Contaminants in Low Permeability Formations

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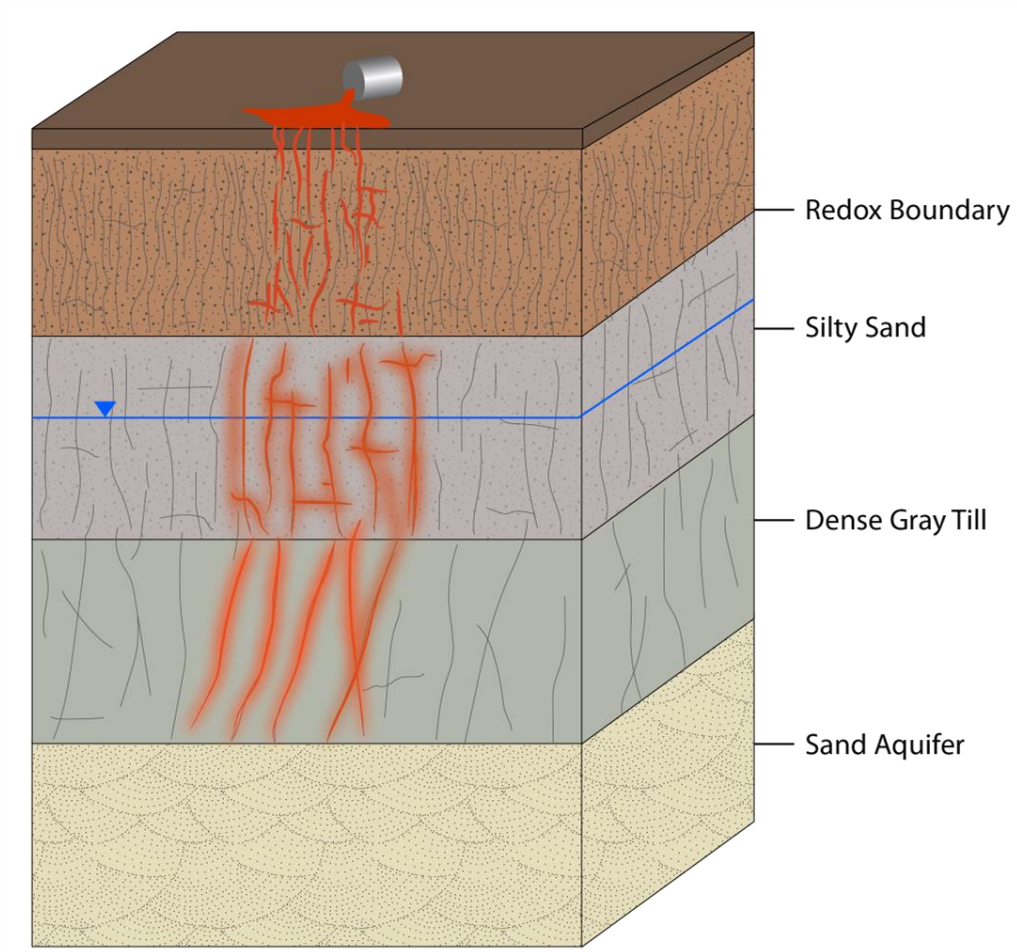
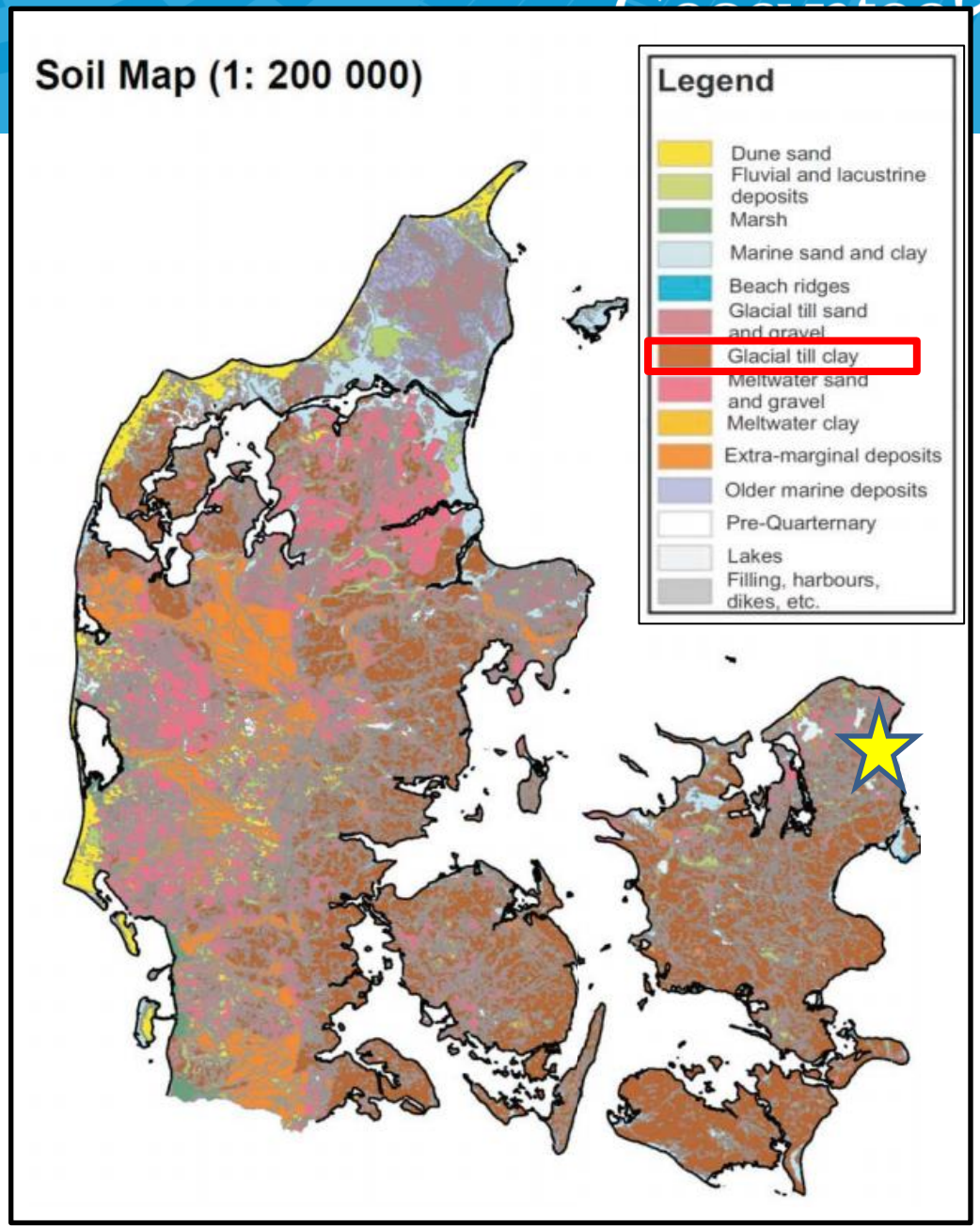
**Low permeability formations <or> bedrock** + **solvents** = **long-term source zones**



## Method development partially funded by Danish government. Why?

- 40% Denmark covered in clay till.




Source: Karin Margarita Frei (2012) Exploring the potential of the strontium isotope tracing system in Denmark, Danish Journal of Archaeology, 1:2, 113-122, DOI: 10.1080/21662282.2012.760889

# Initial Development Spanned Three Pilot Tests

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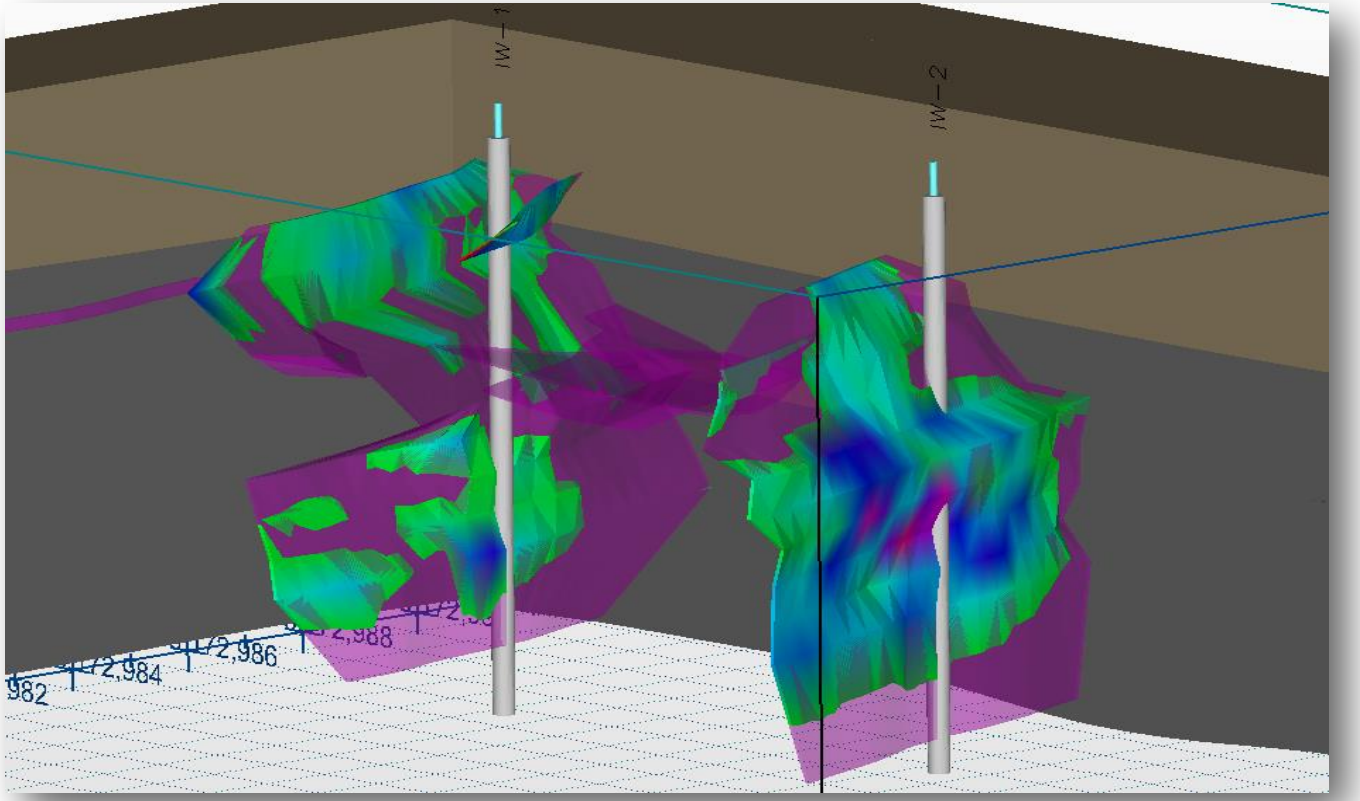
## #1: Large vertical emplacement – surfacing

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## #2: Horizontal emplacement – surfacing

# Initial Development Spanned Three Pilot Tests

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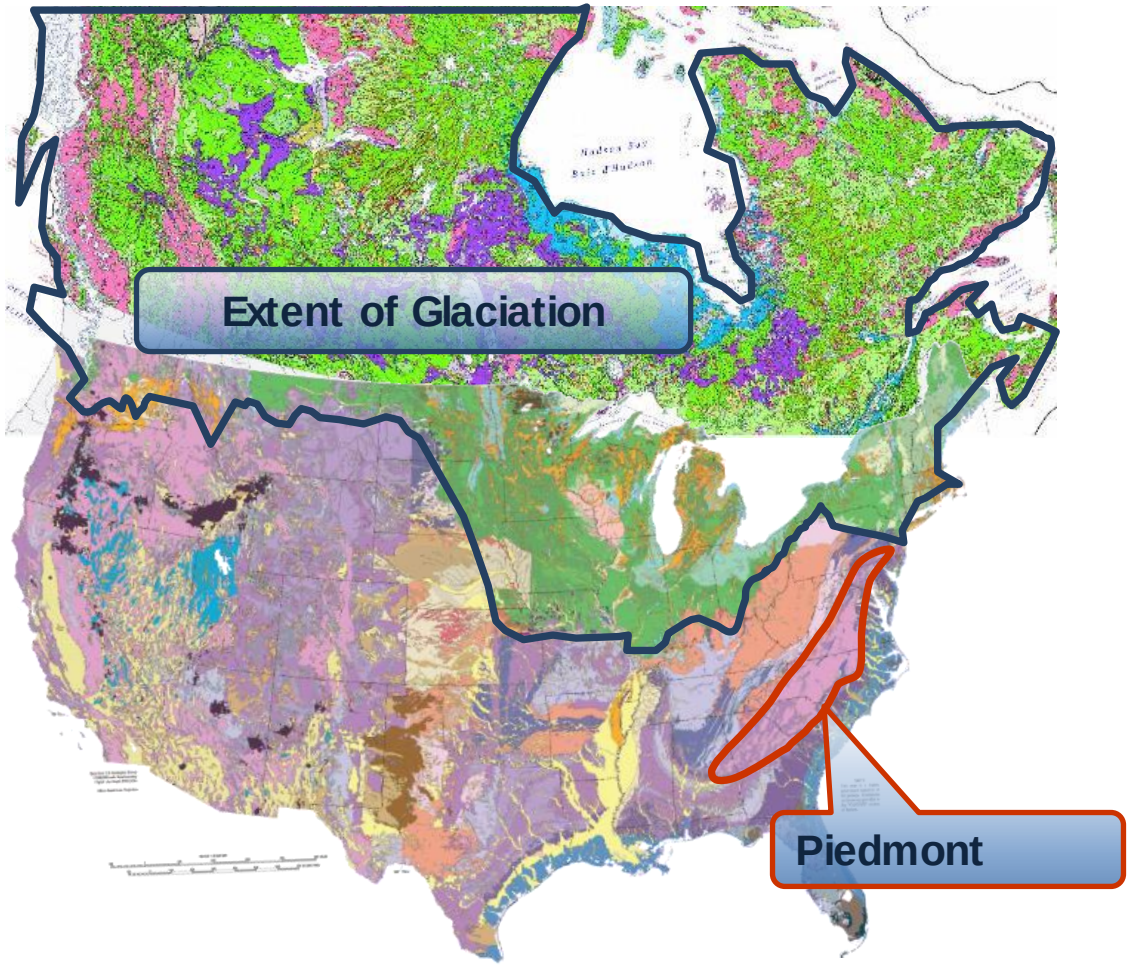
## #3: Large horizontal emplacement – no surfacing

# Applicability in US and Canada:

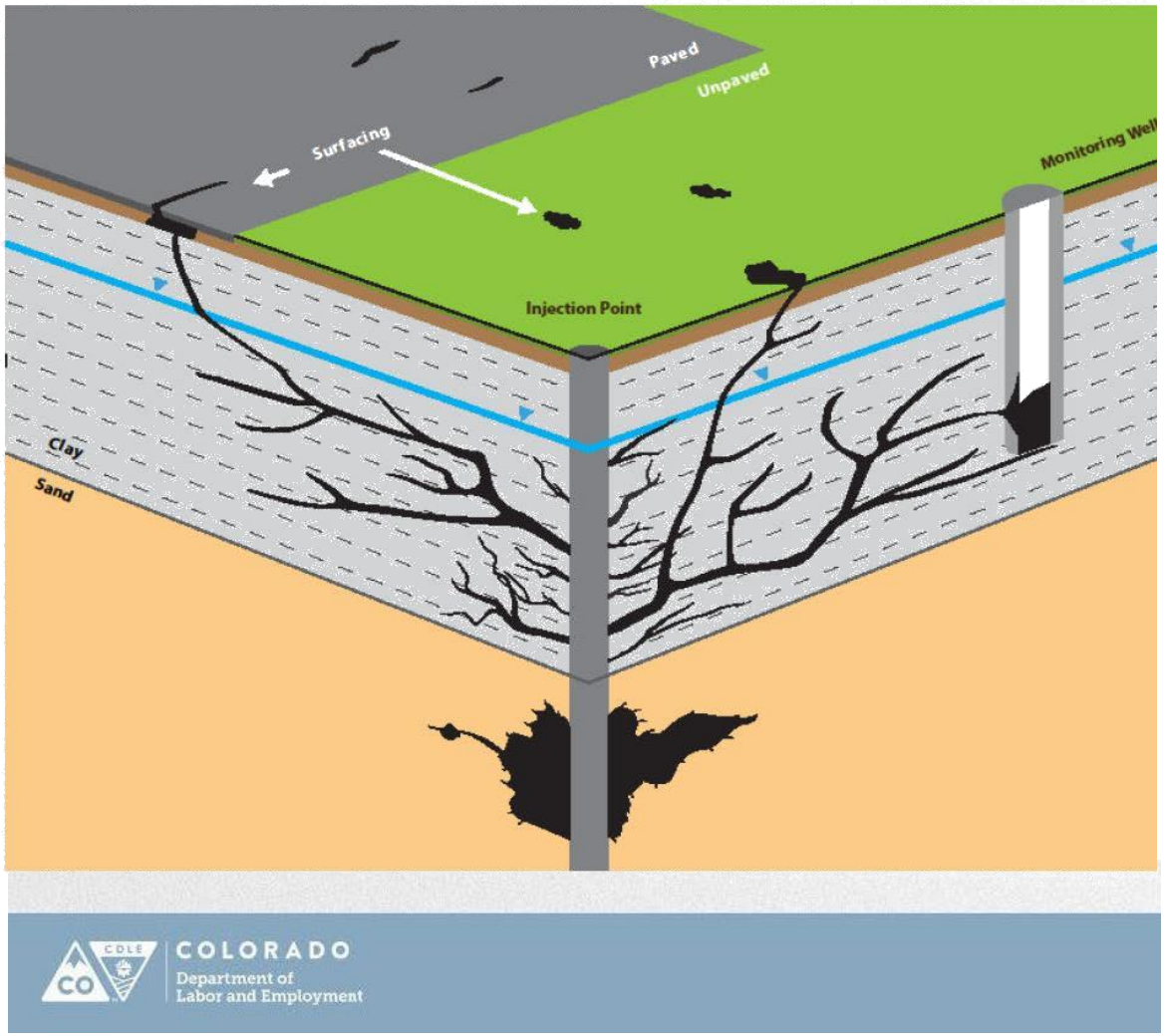
Remediating low-permeability sites is a major challenge for US and Canadian Sites.




**Surficial Geology of North America**

Source:
http://ftp.maps.canada.ca/pub/nrcan_rncan/publications/ess_sst/295/295462/gsccgm%5f195%5fb%5f2014%5fmn01p1.pdf
http://pubs.usgs.gov/of/2003/of03-275/USGS_OFR03-275.pdf

# Jet Injection Compared to Traditional DPT Injections




- Injecting remediation amendment slurries using traditional direct push methods often results in uncontrolled fracturing of the subsurface.
- DPT Jet Injection overcomes this limitation.

# Jet Injection – Treatment Concepts

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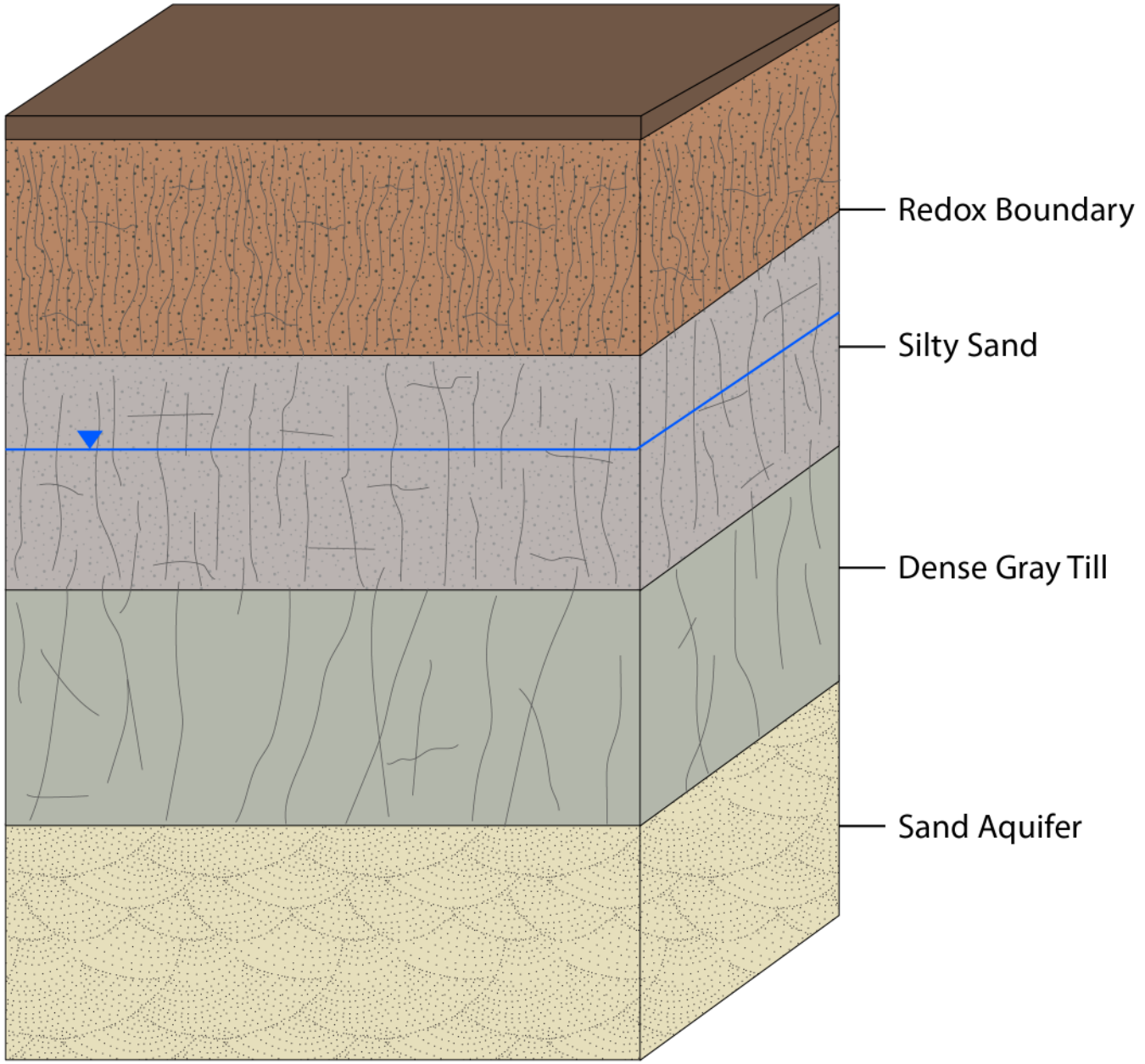
# Conceptual Model – Treatment with DPT Jet Injection



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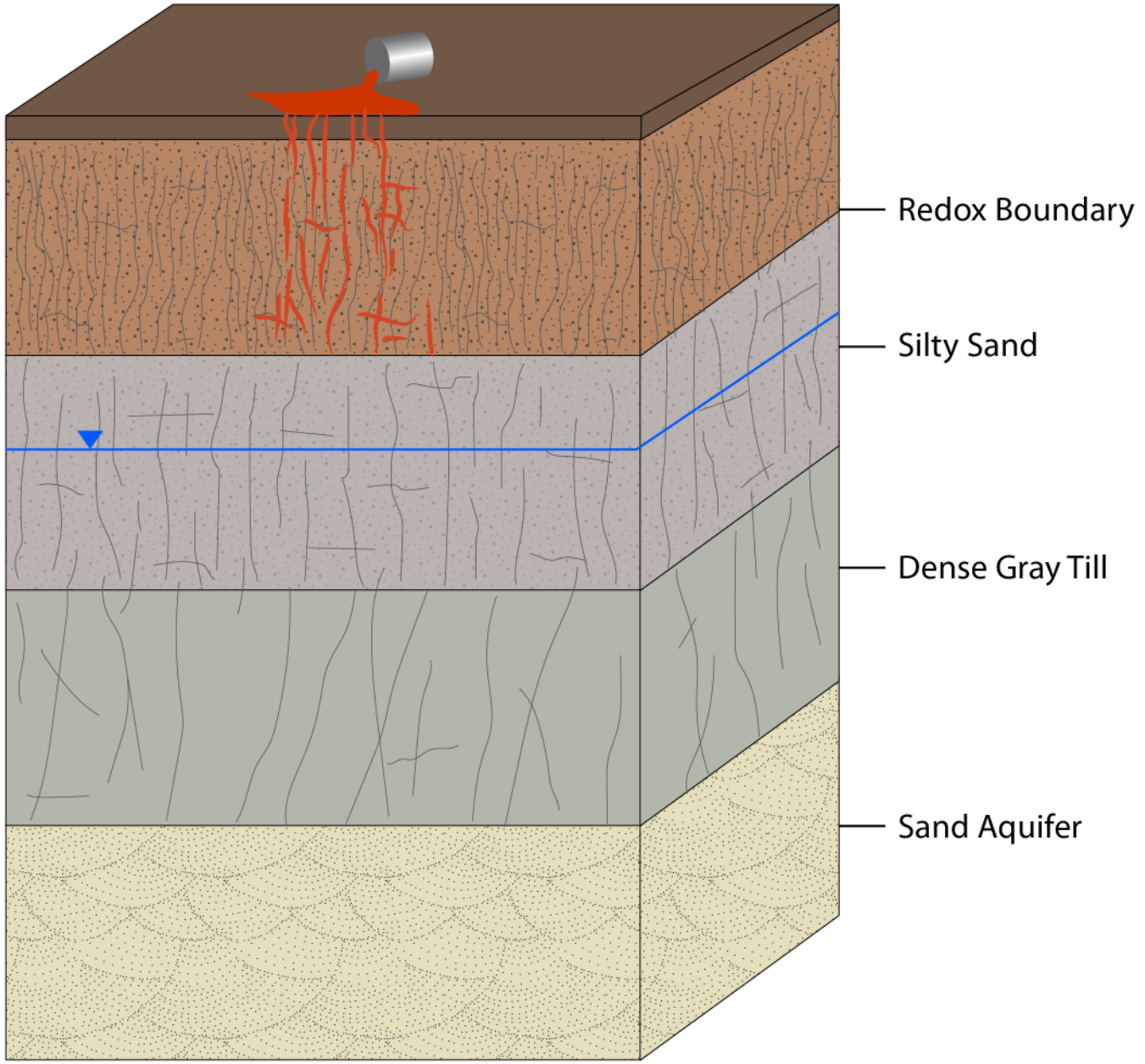

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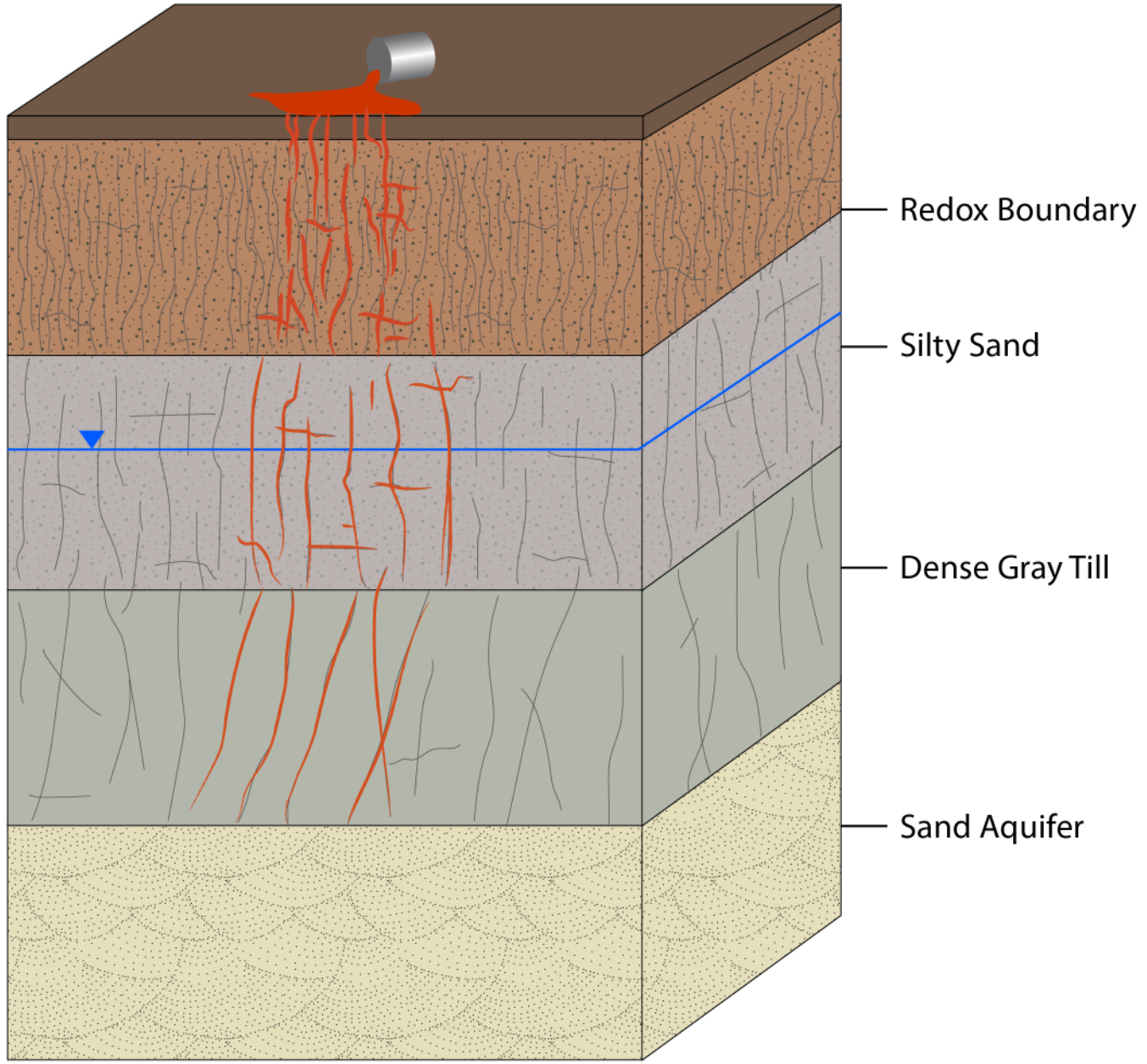

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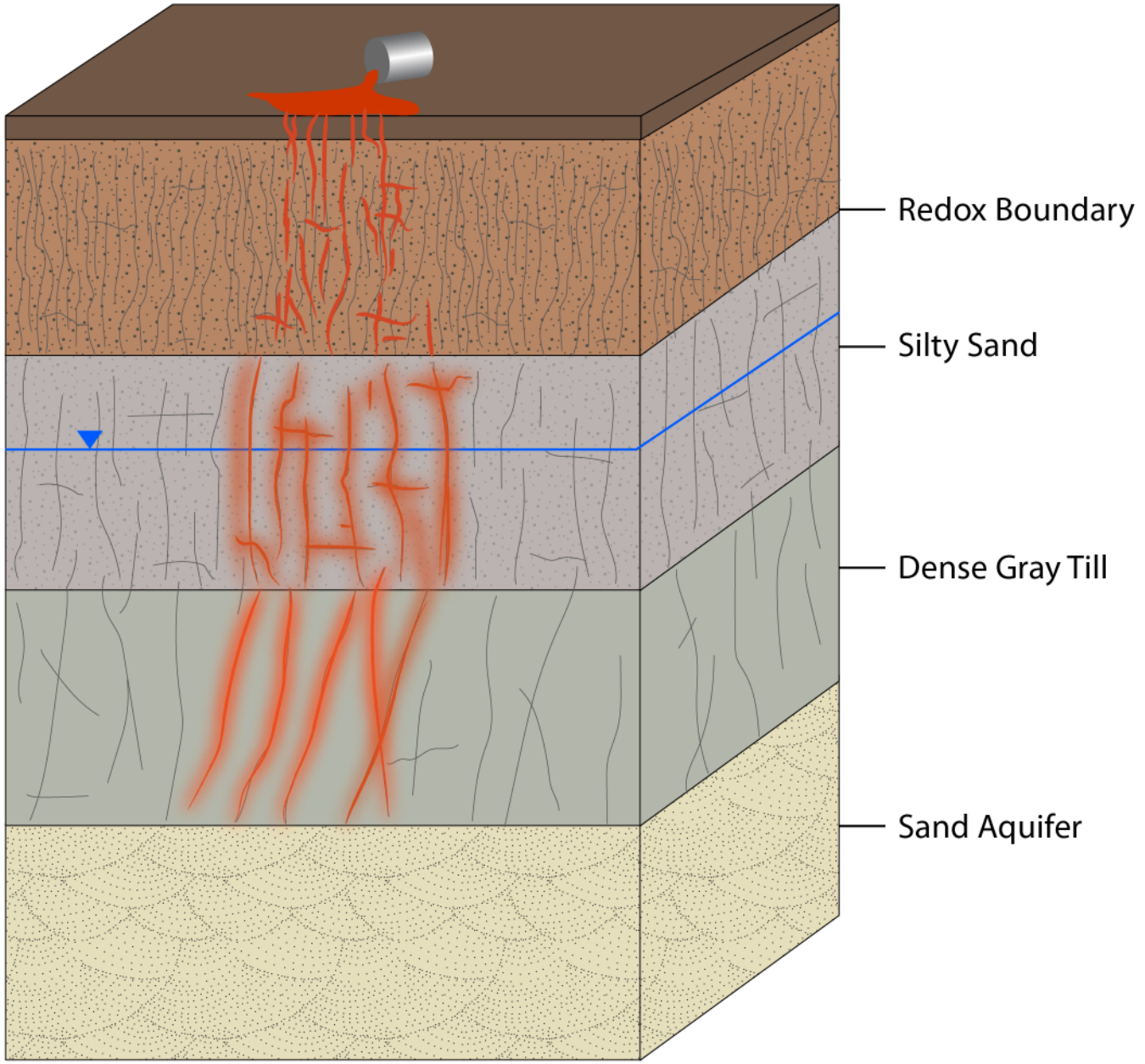

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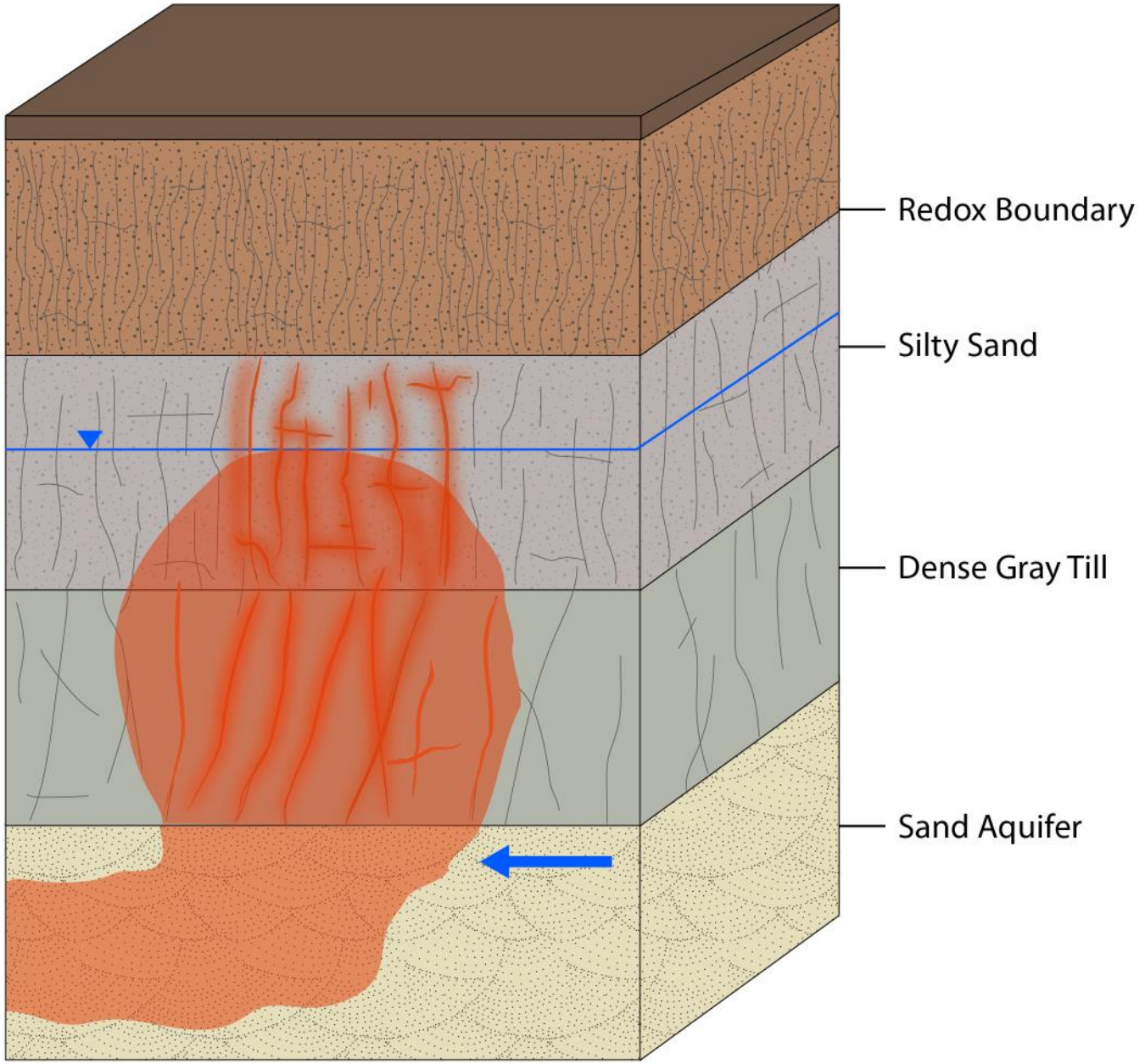

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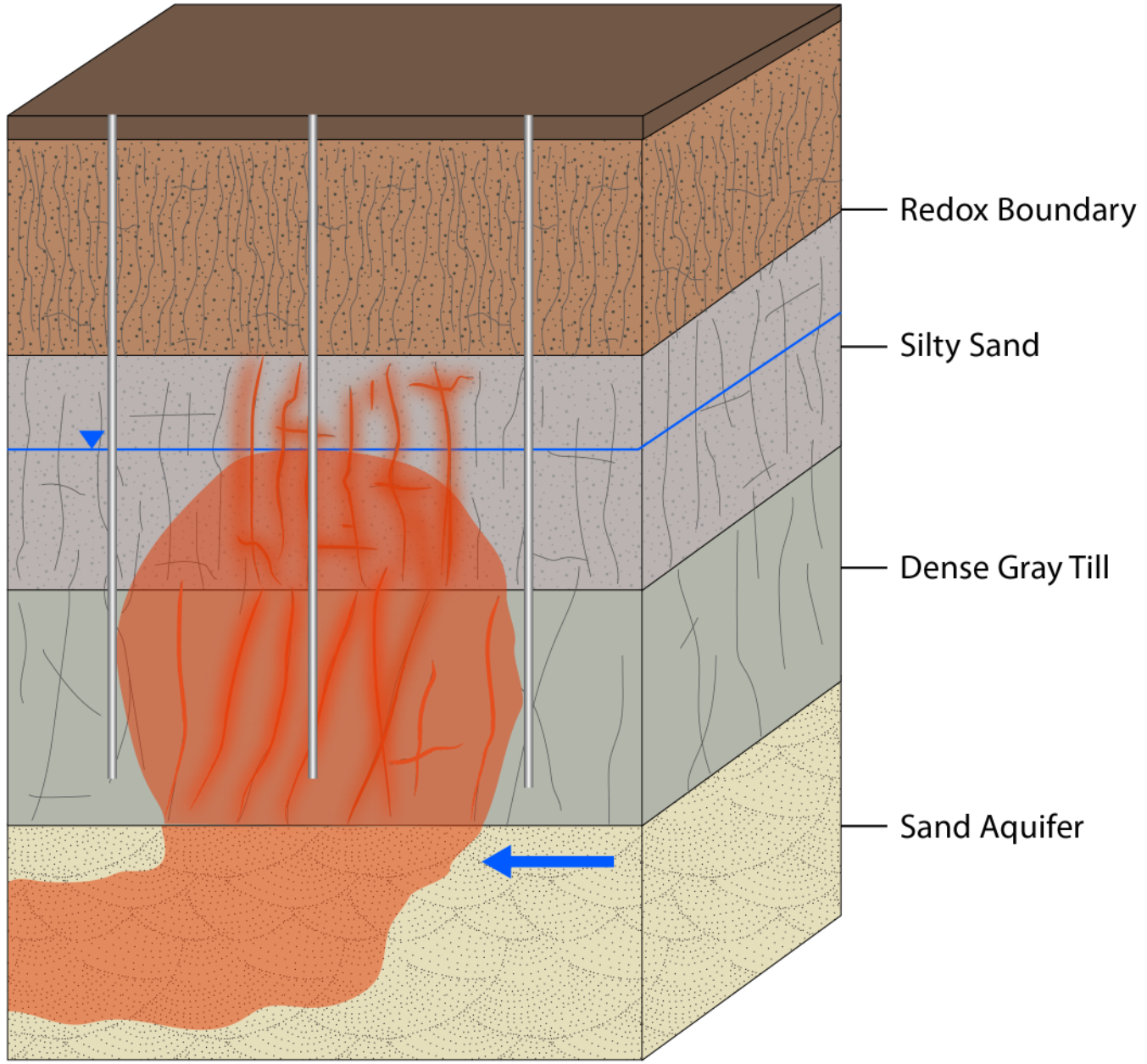

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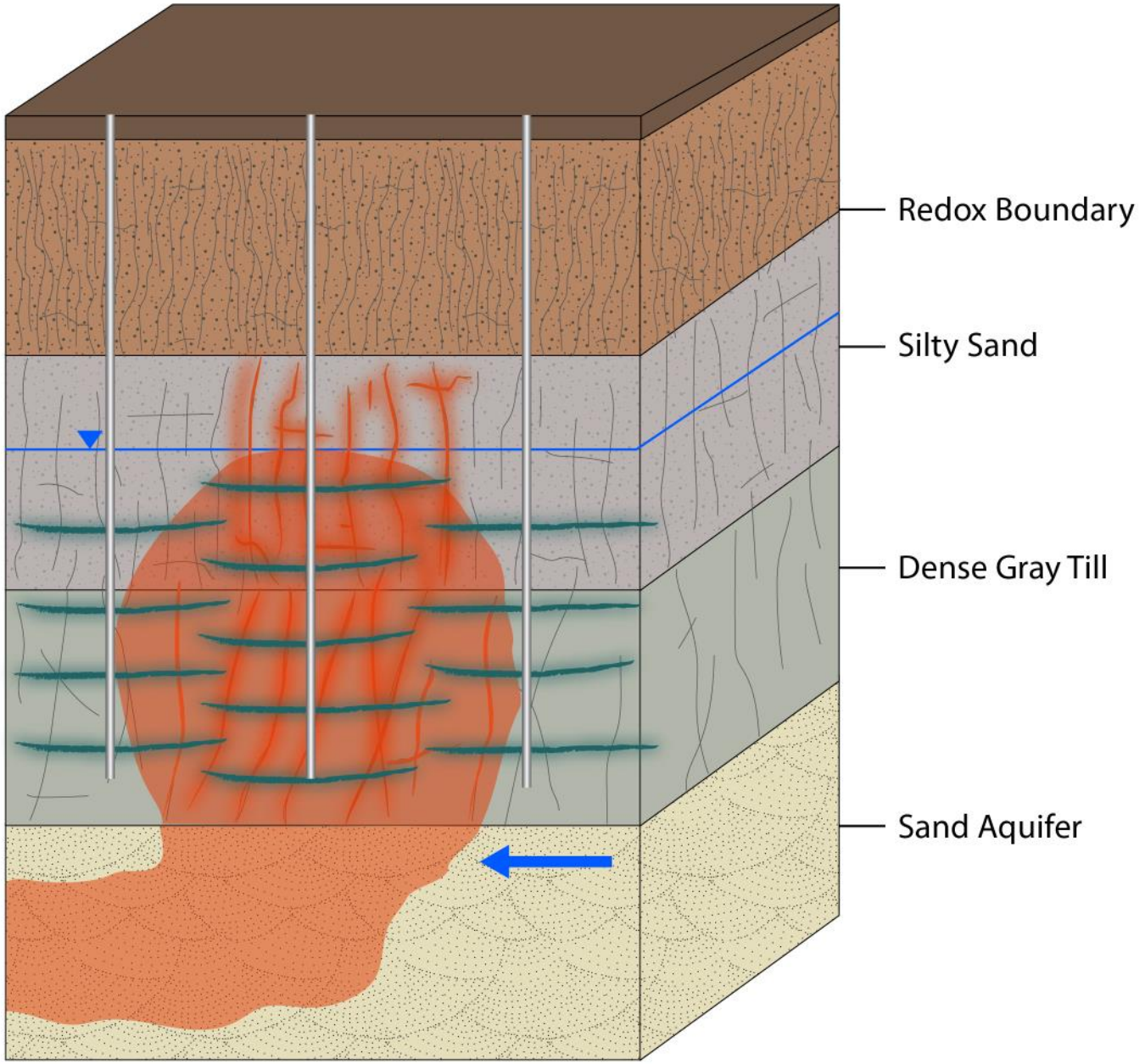

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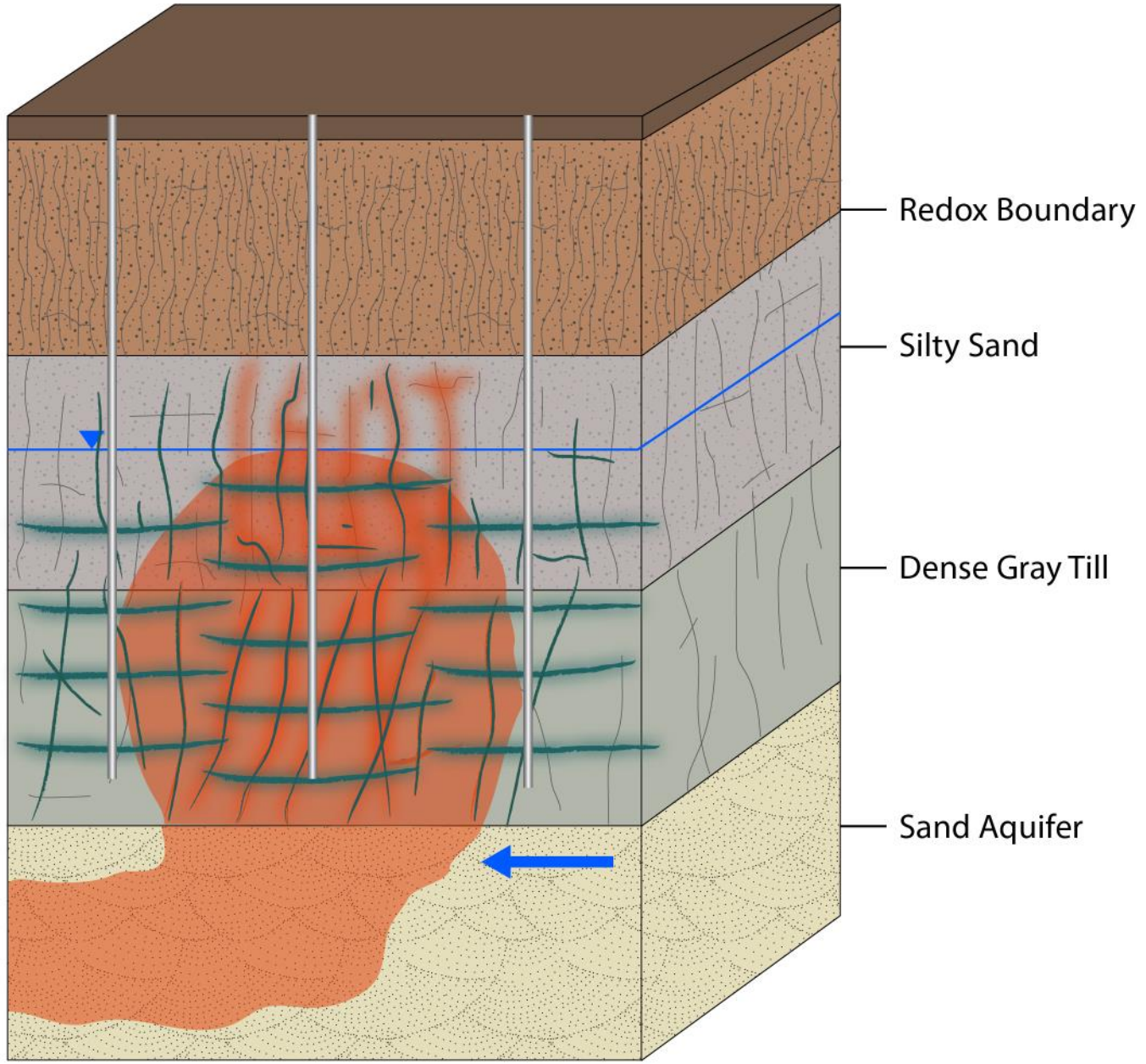

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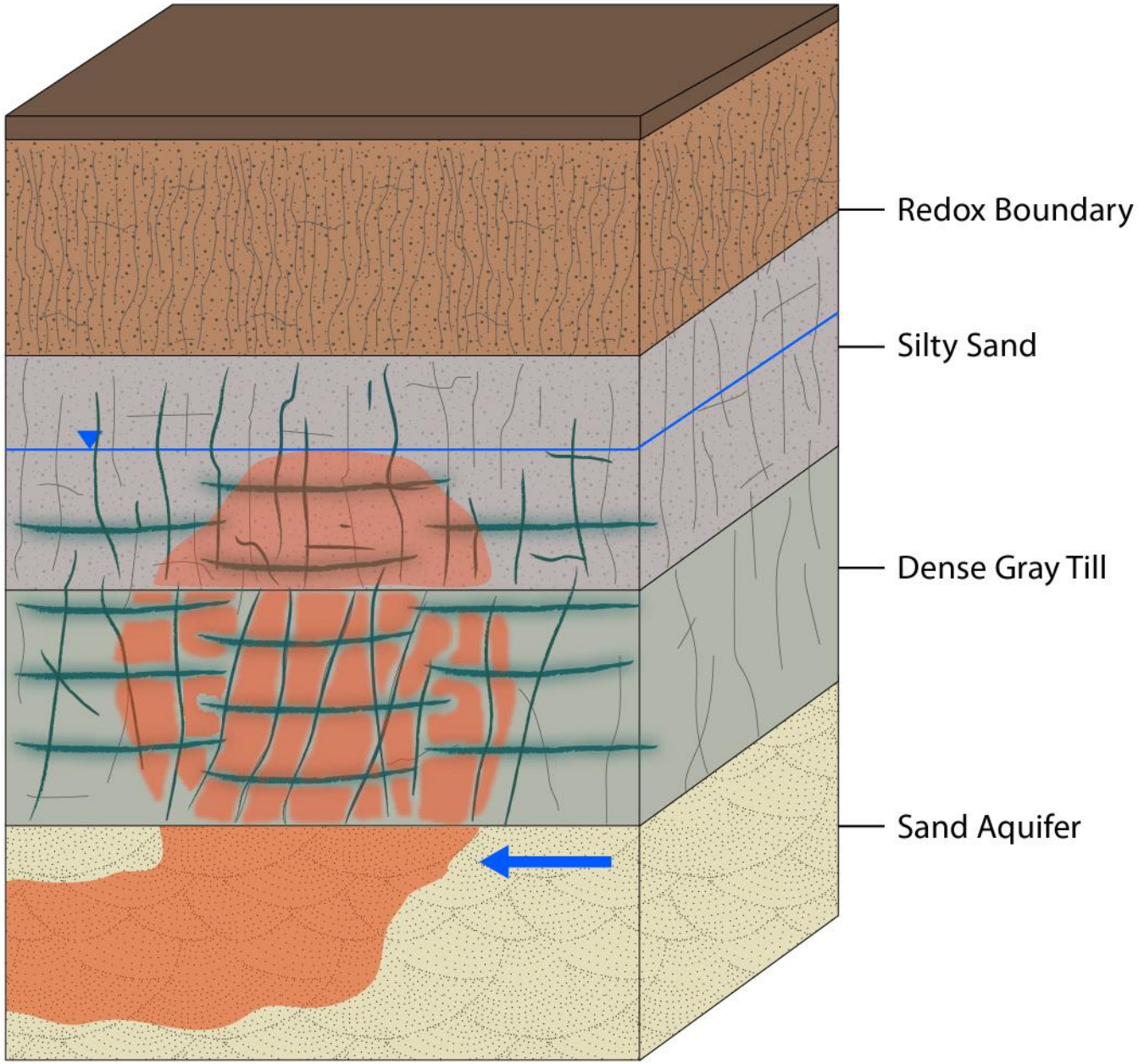

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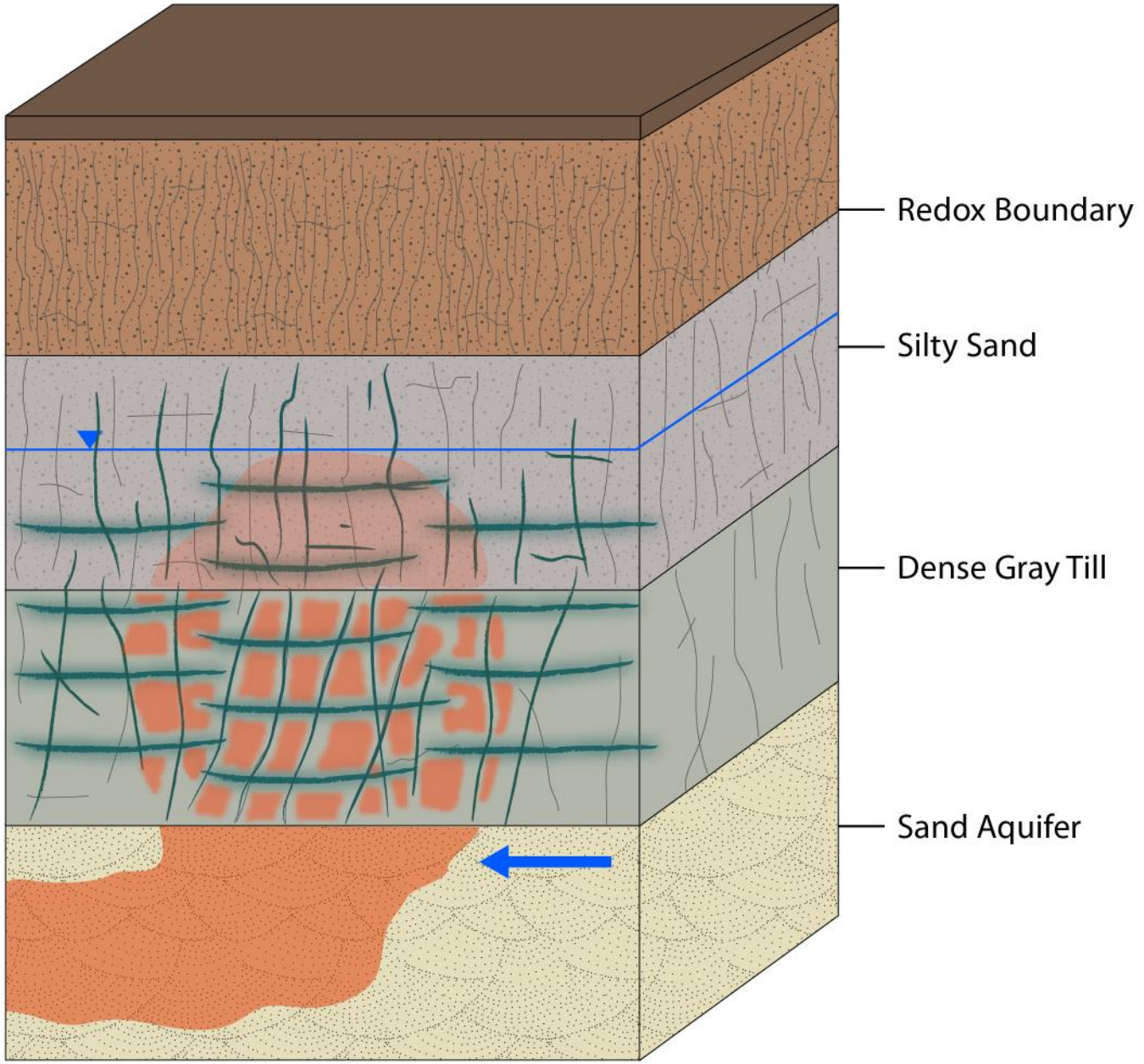

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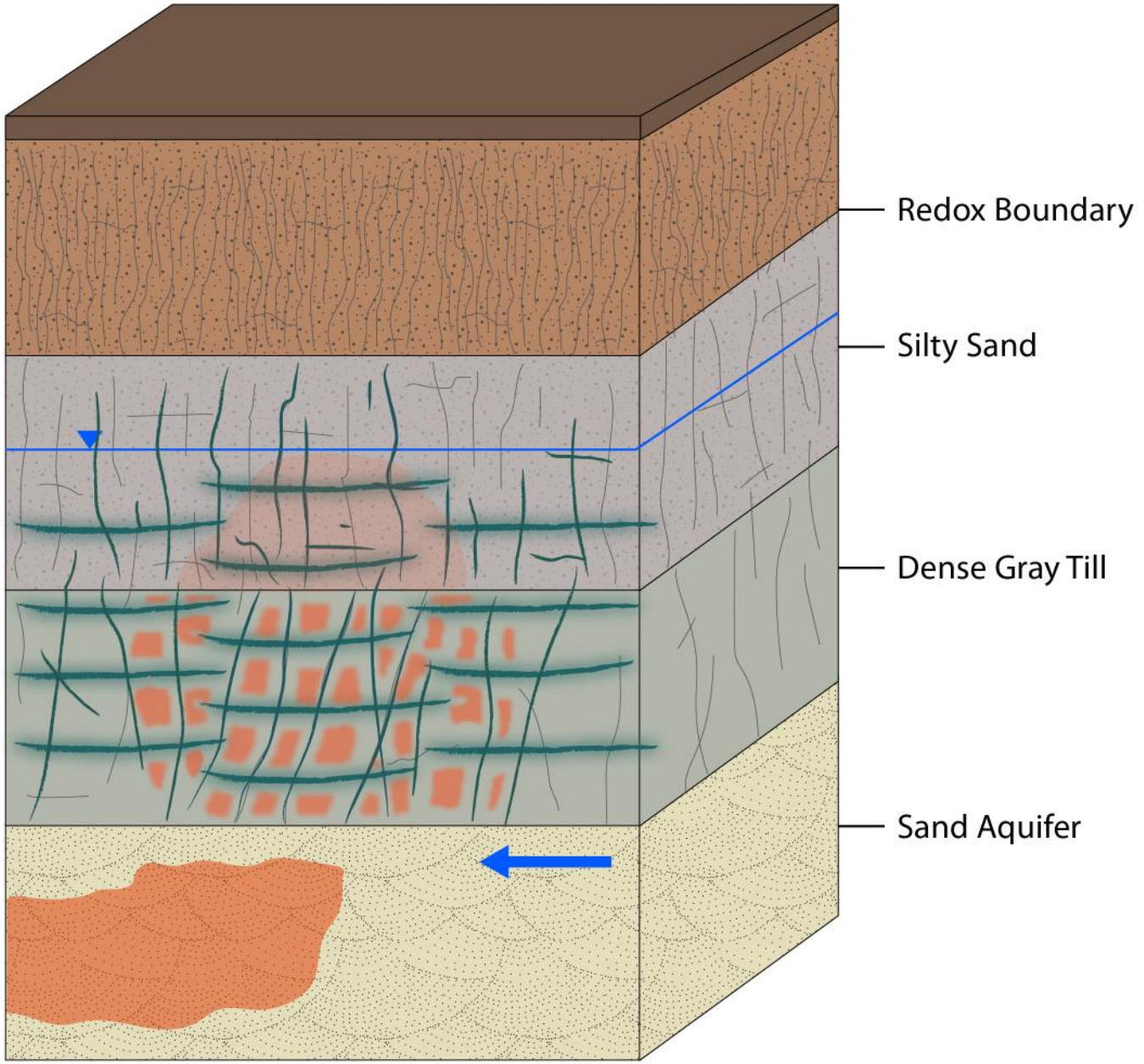

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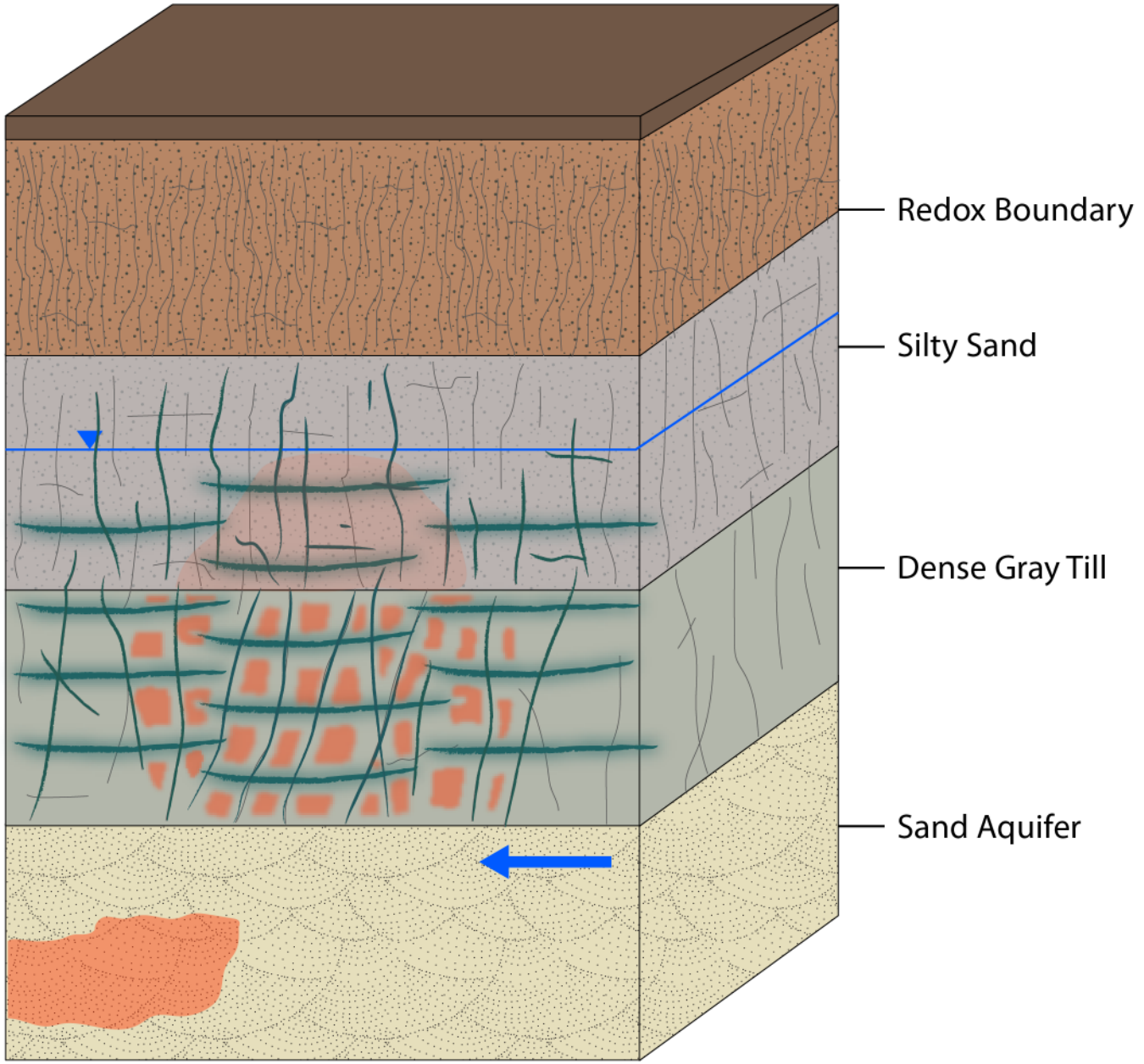

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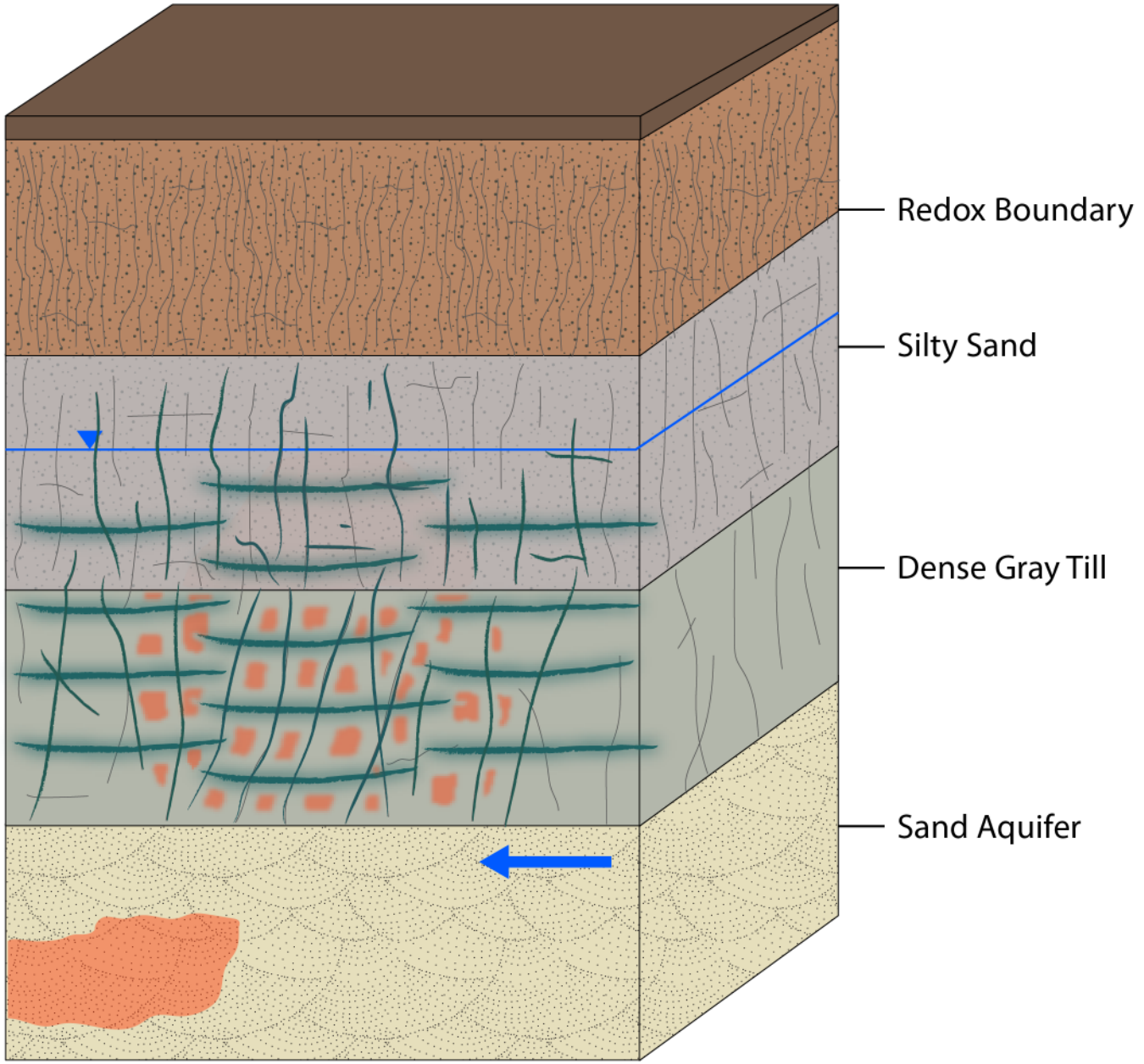

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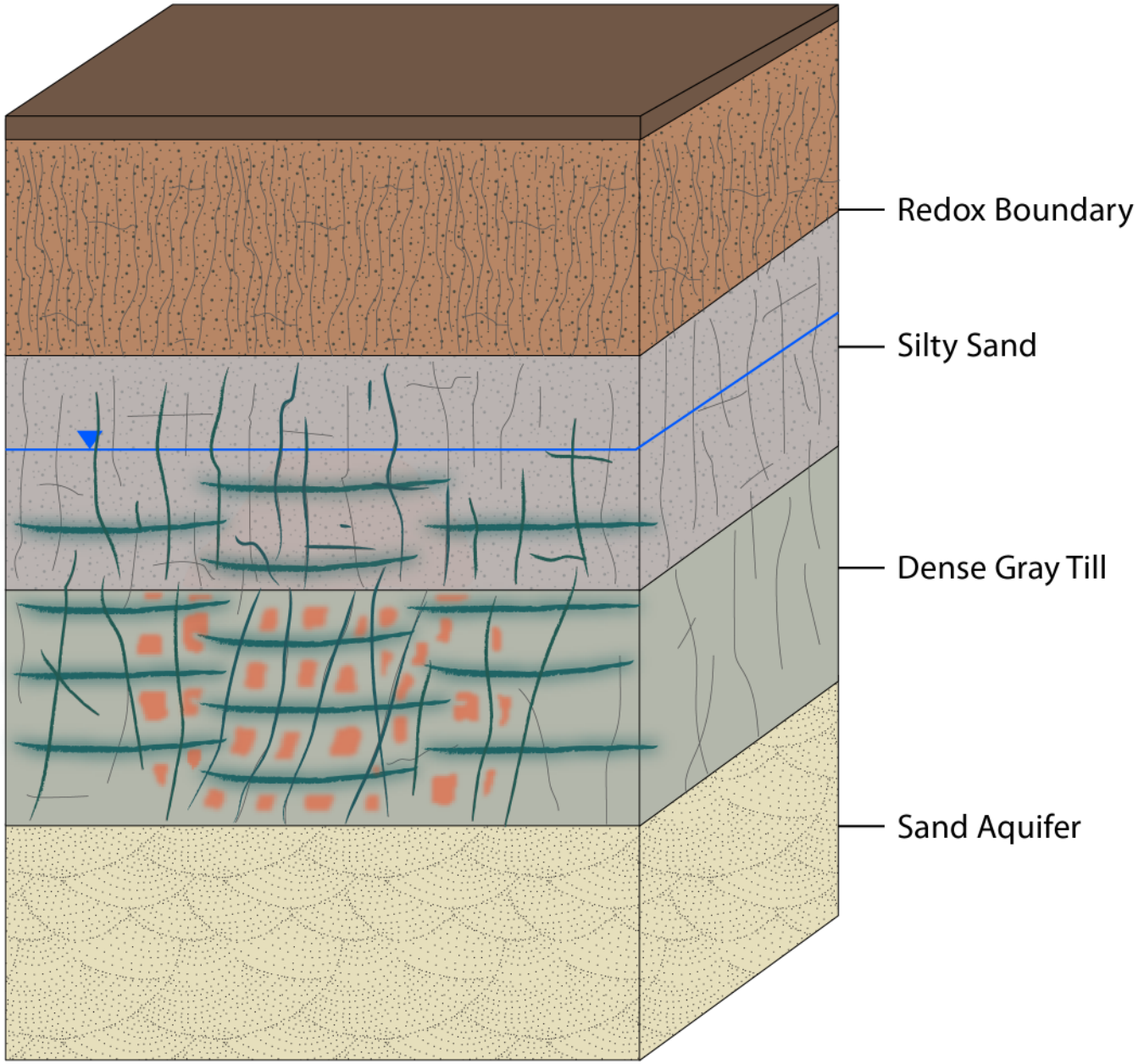

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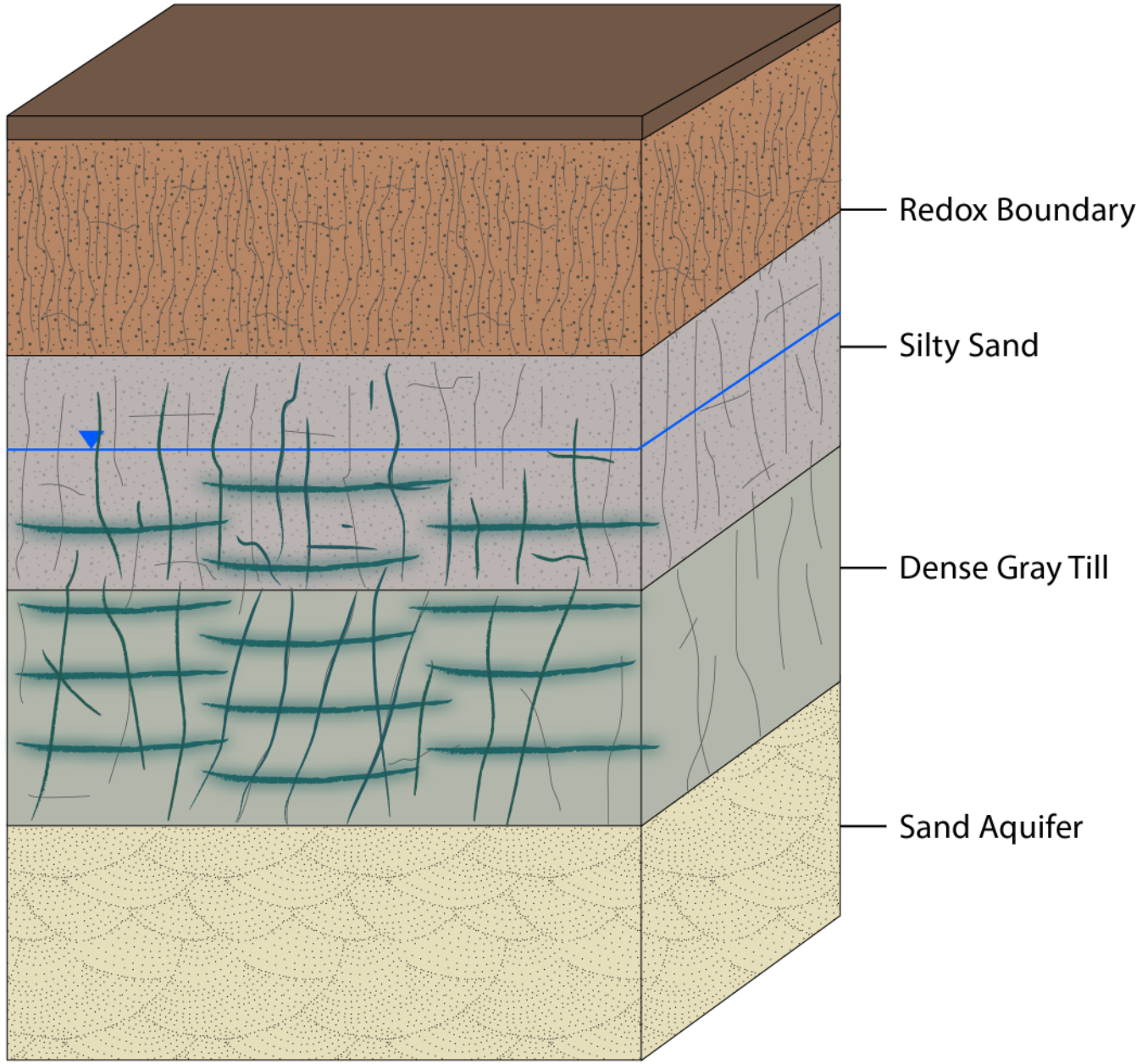

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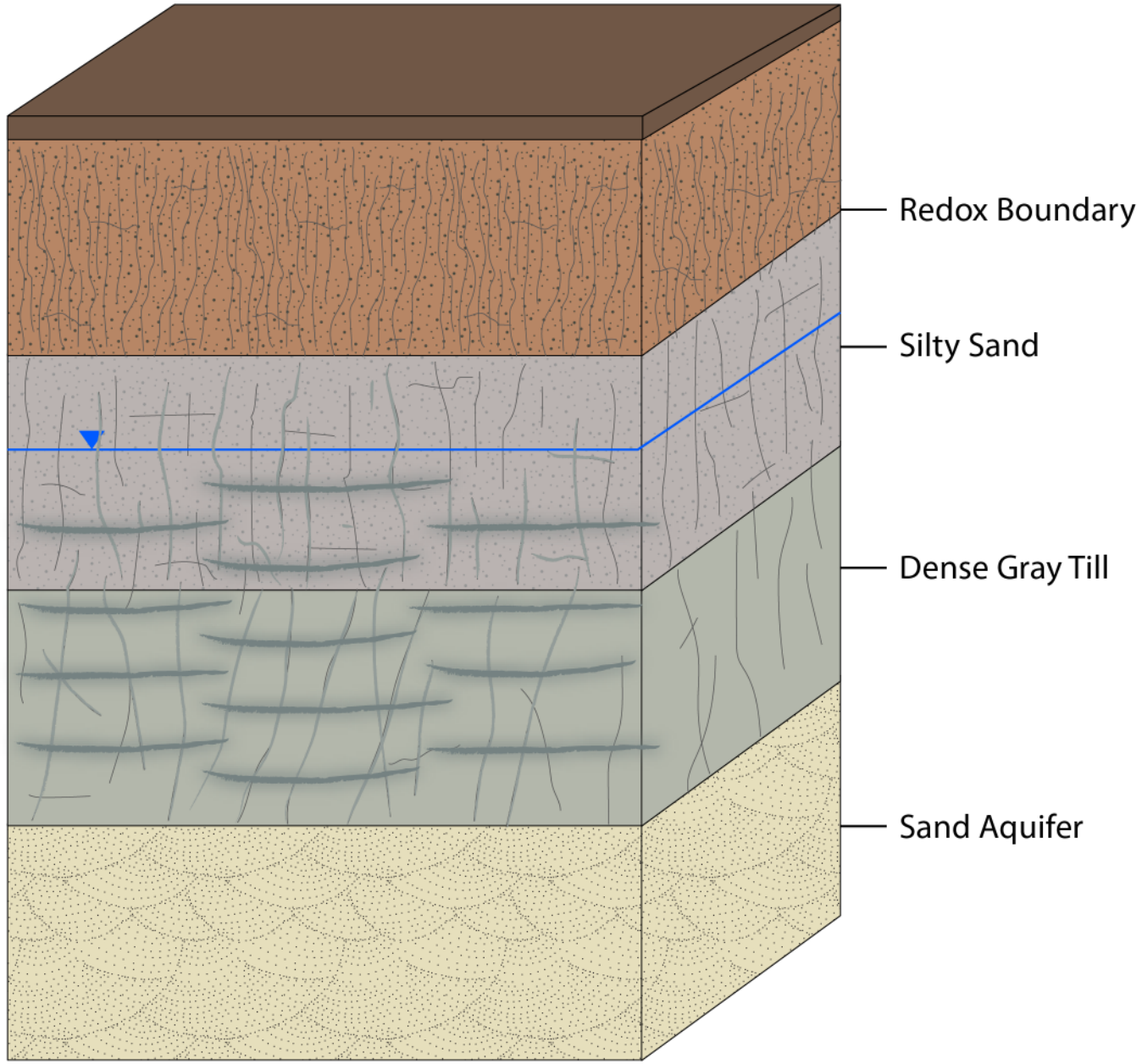

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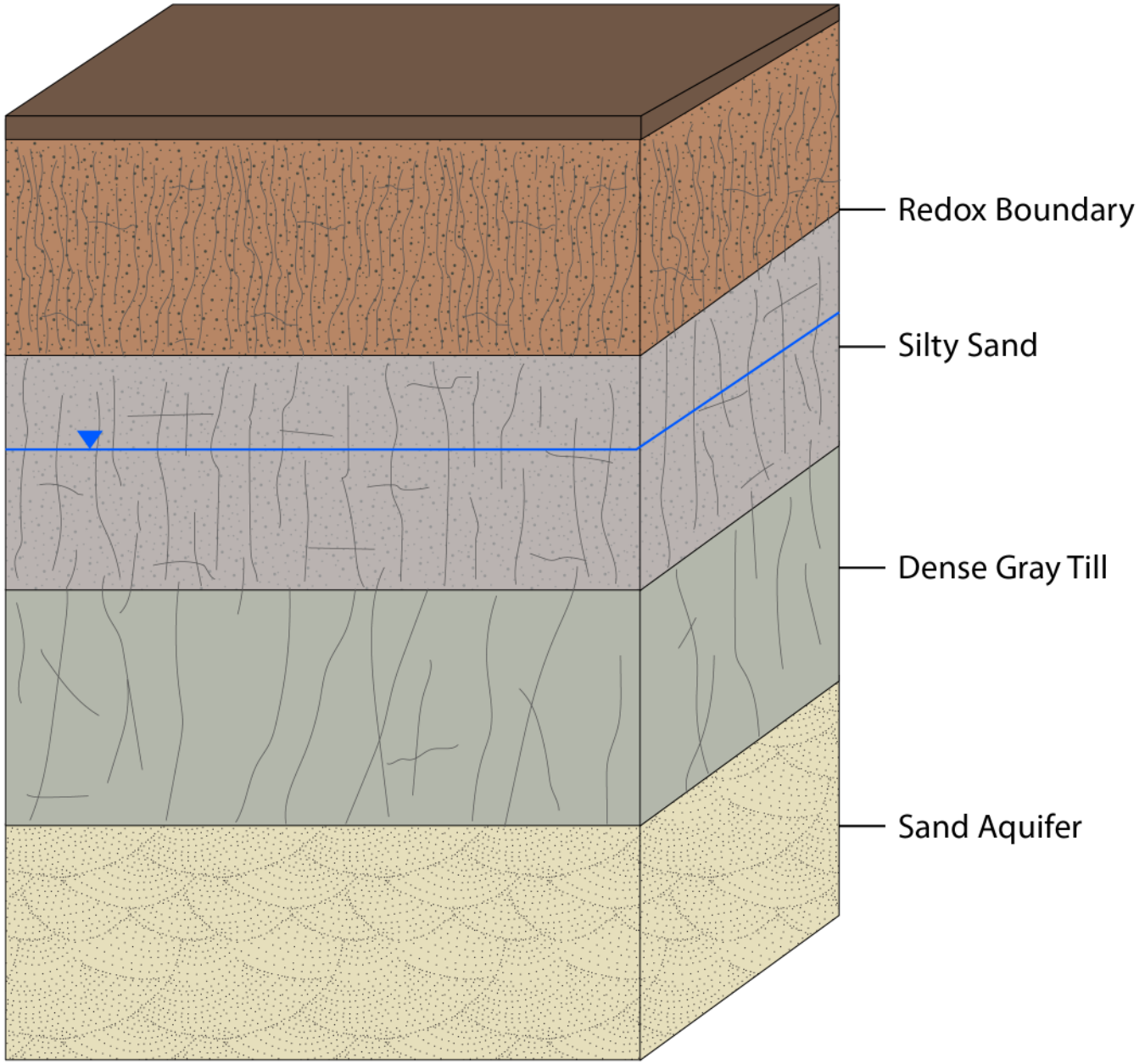
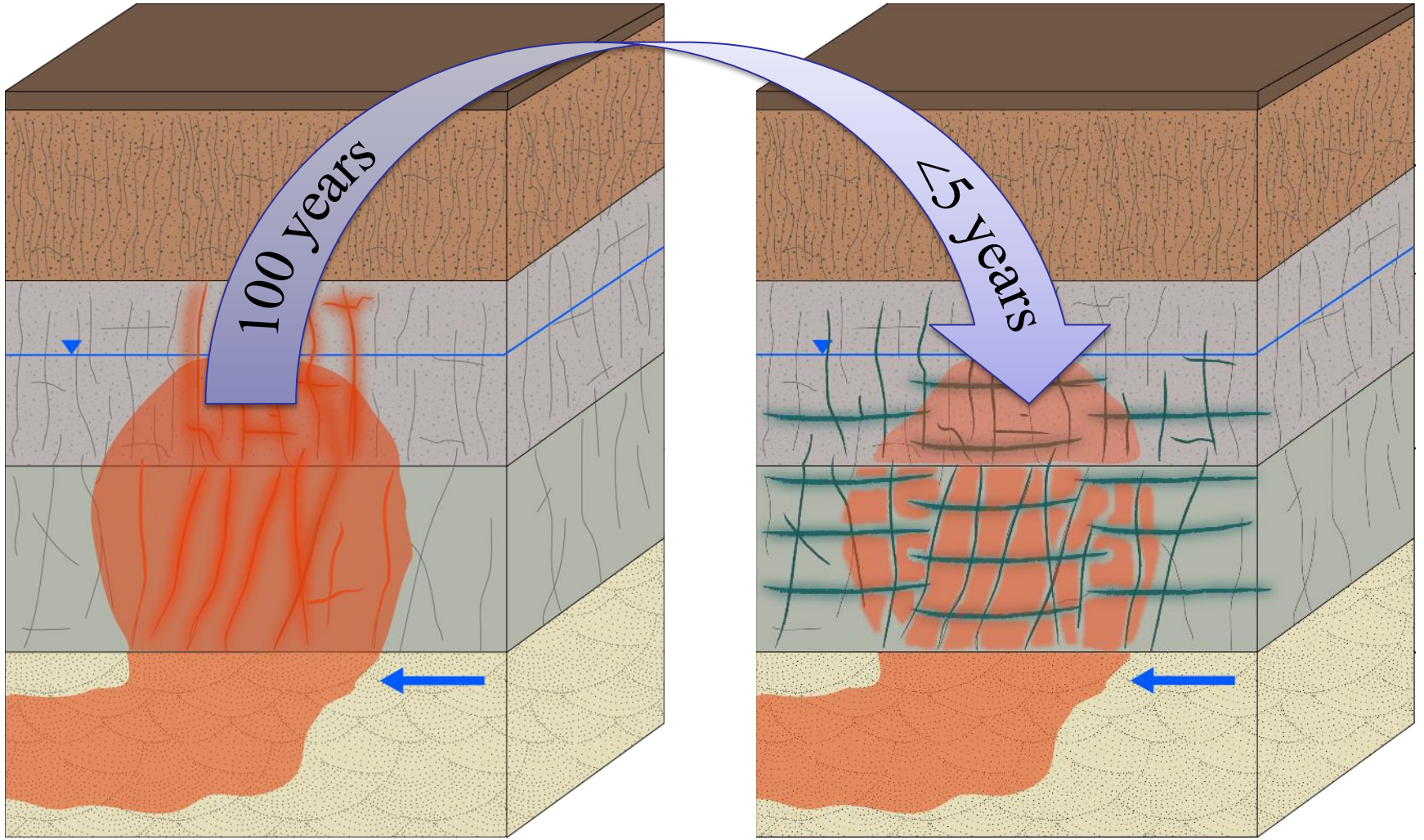


# Objective



# DPT Jet Injection – How does it work?

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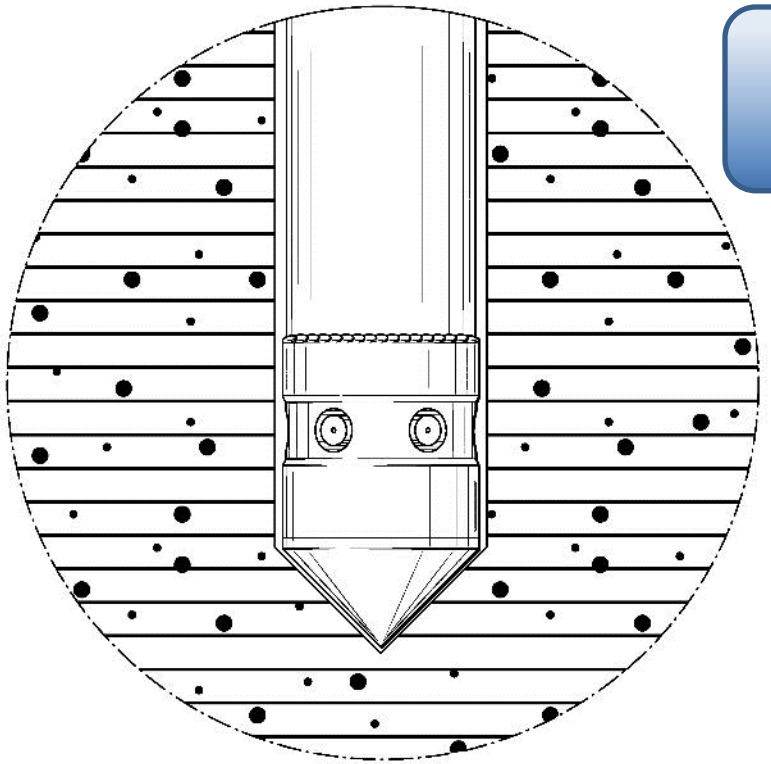
# DPT Jet Injection – How Does it Work?



**Direct push tooling advancement**

# DPT Jet Injection – How Does it Work?

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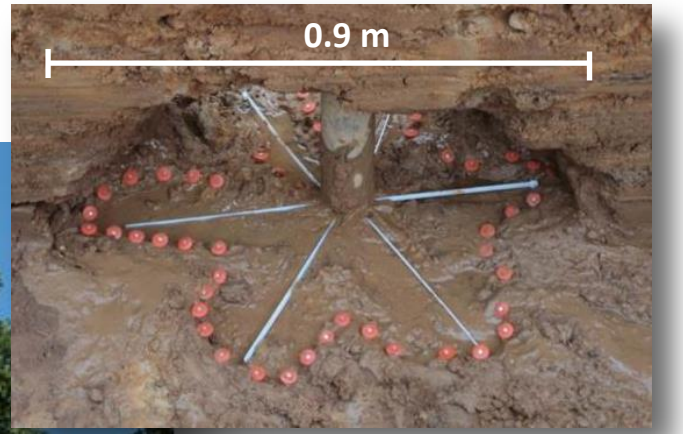


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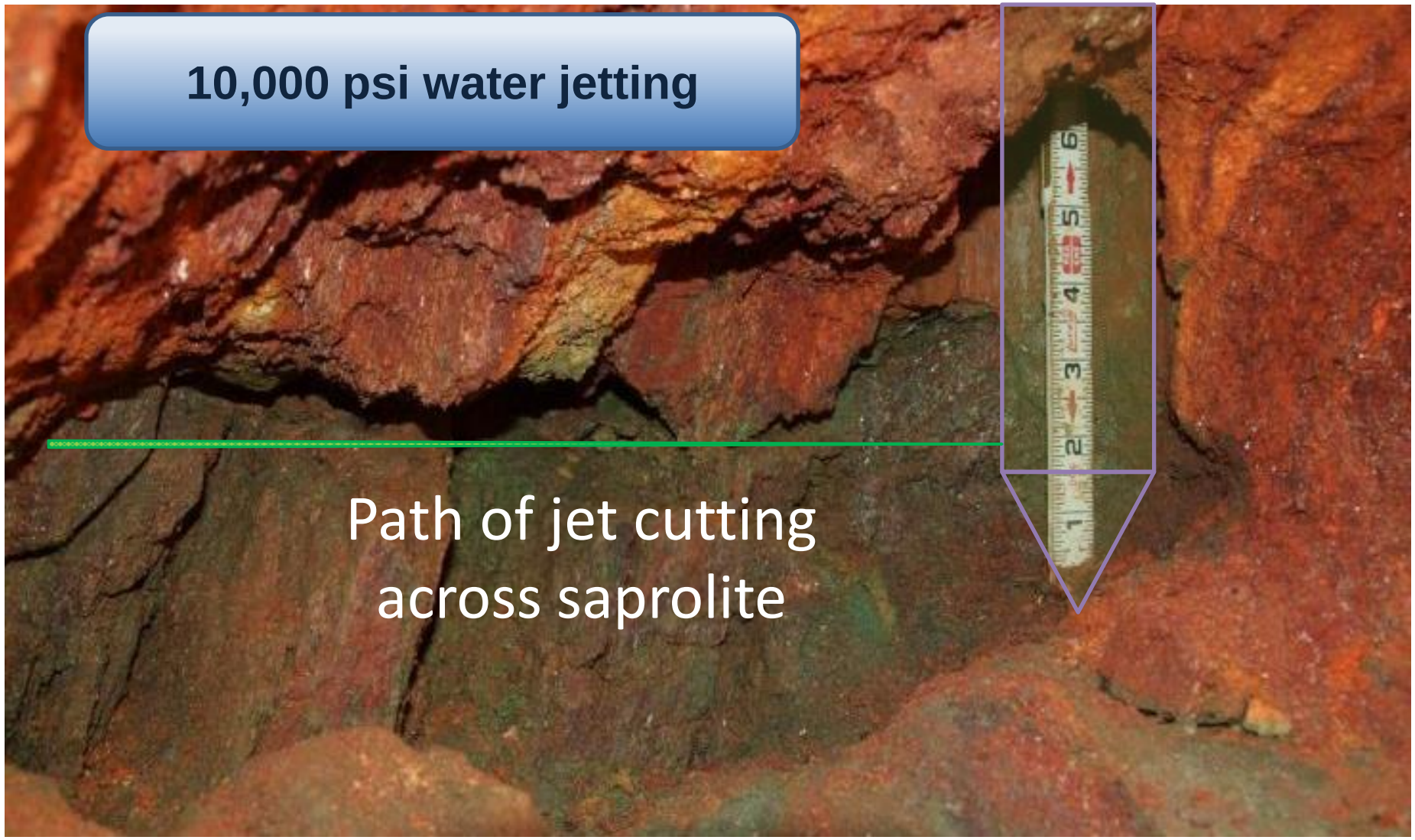

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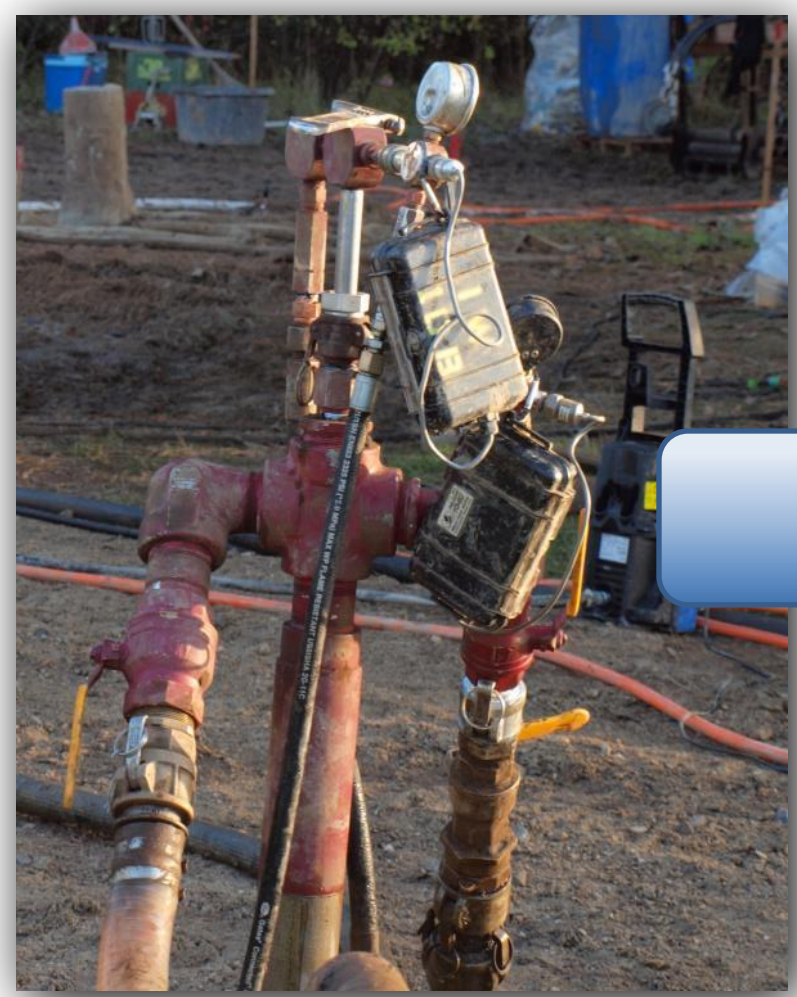

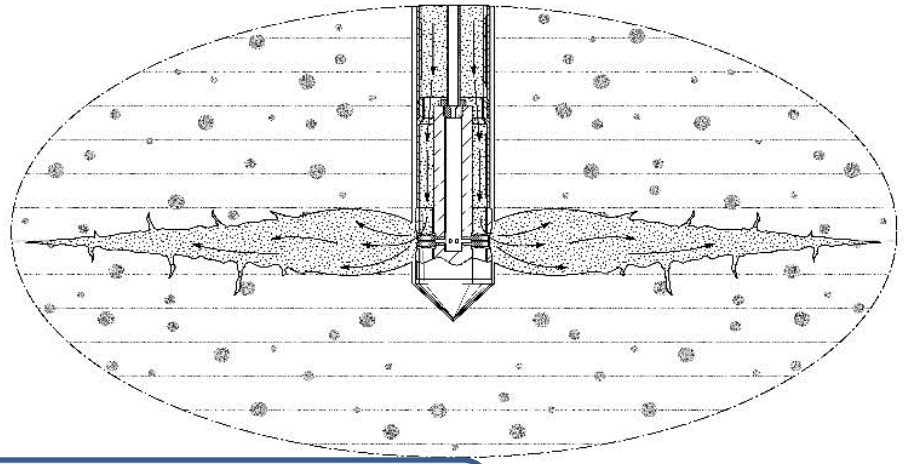

**100 to 400+ psi slurry injection**

# DPT Jet Injection – How Does it Work?

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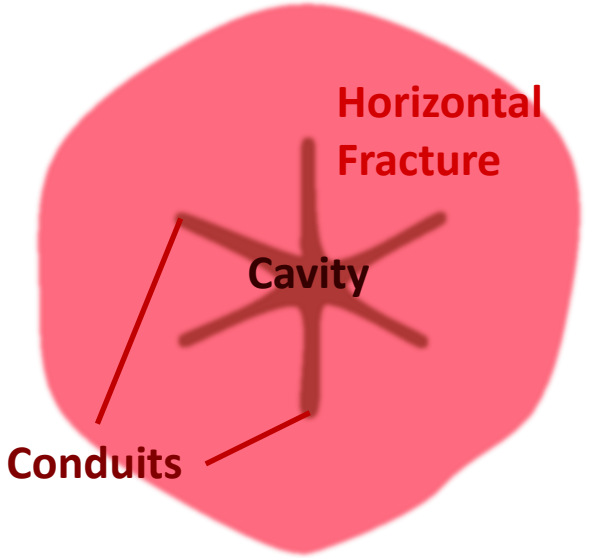
**Slurry contains solid proppant which is emplaced to create a reactive and more permeable zone.**




# CASE STUDY: Full-scale Source Treatment in Denmark

# **Case Study:** Remedial Design

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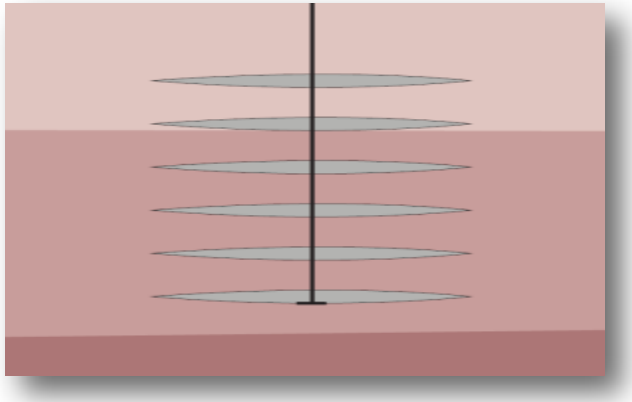
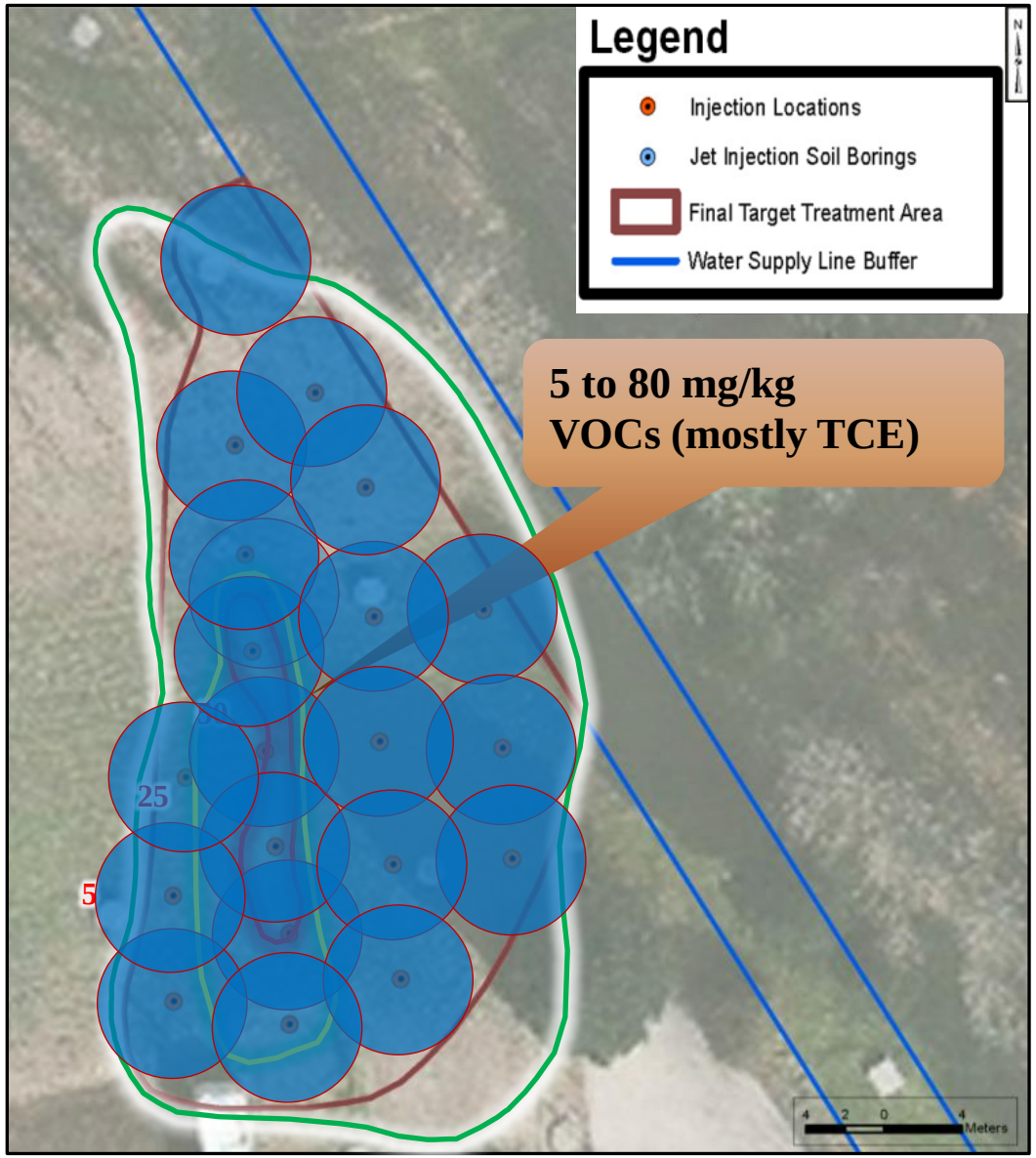
- 700 sq meter Target Treatment Area (TTA)
- 4 m design ROI
- 21 injection locations with 121 individual injections
- 5-7 discrete injection depths
- 50 tonnes mZVI (Hepure Ferox Flow)
- 25 tonnes sand





# **Case Study:** Denmark – ZVI Distribution

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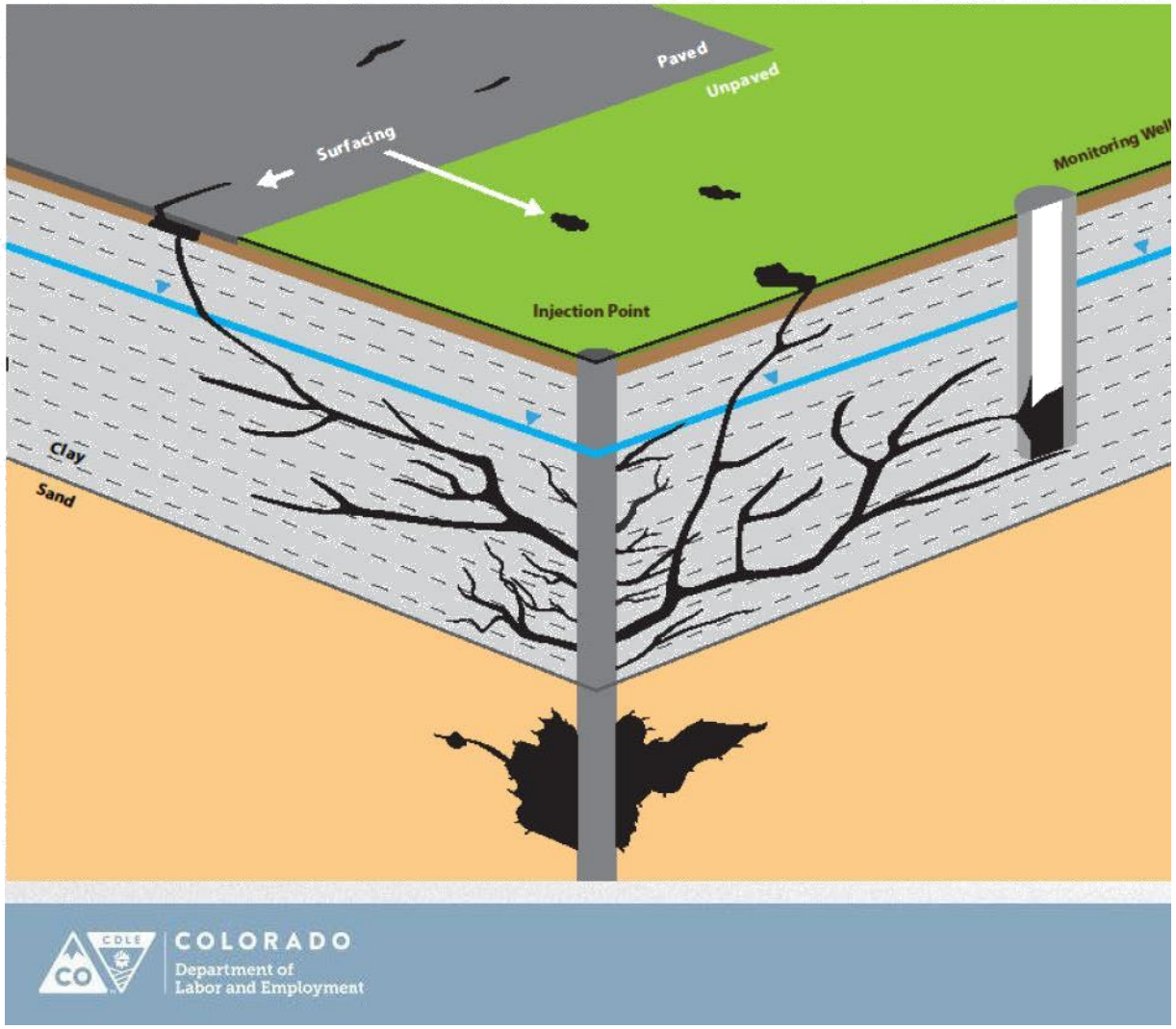
# **Case Study:** Surfacing

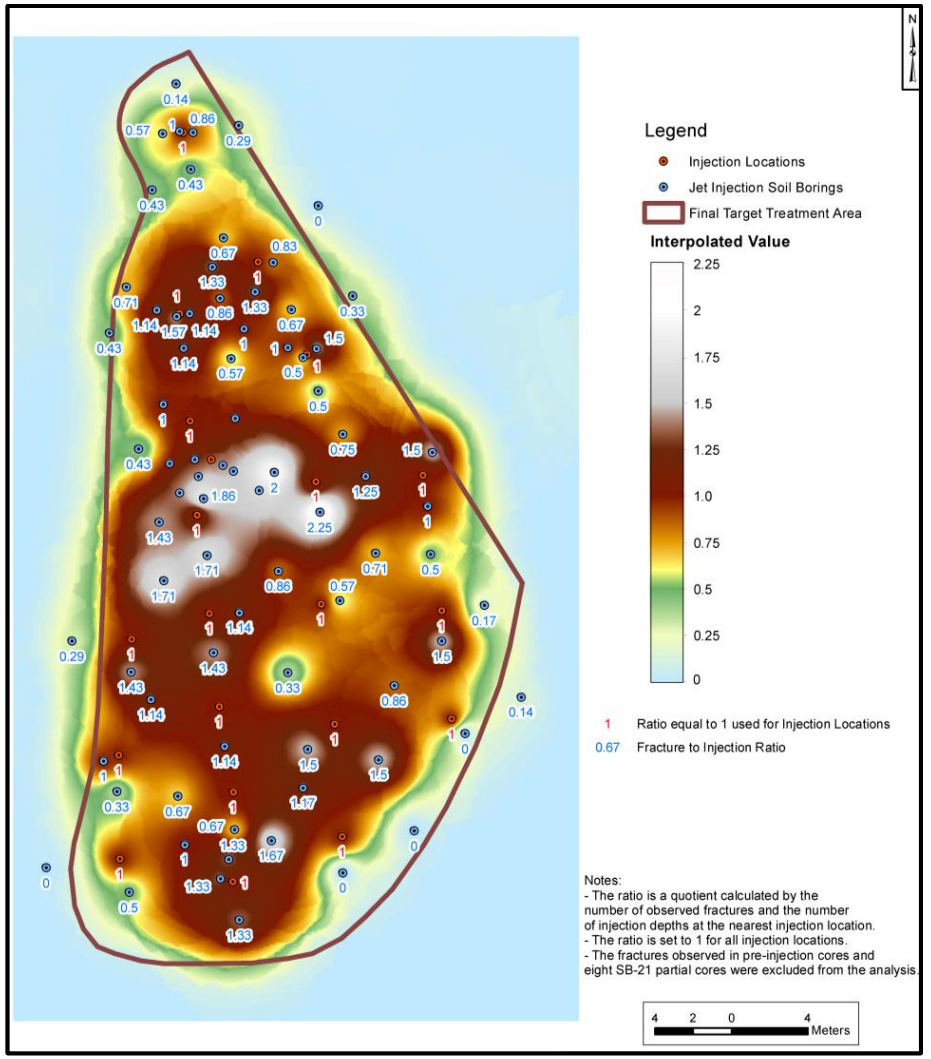



Surfacing limited to 4 known historical borings and 2 other locations during 121 injections.

Surfacing during slurry injection can be controlled!

# Case Study – Lateral Fracture Distribution

- Advanced 80 borings in Target Treatment Area (TTA)
- Confirmed that we met our 4 m design ROI



# Case Study: Tracing Single Fractures

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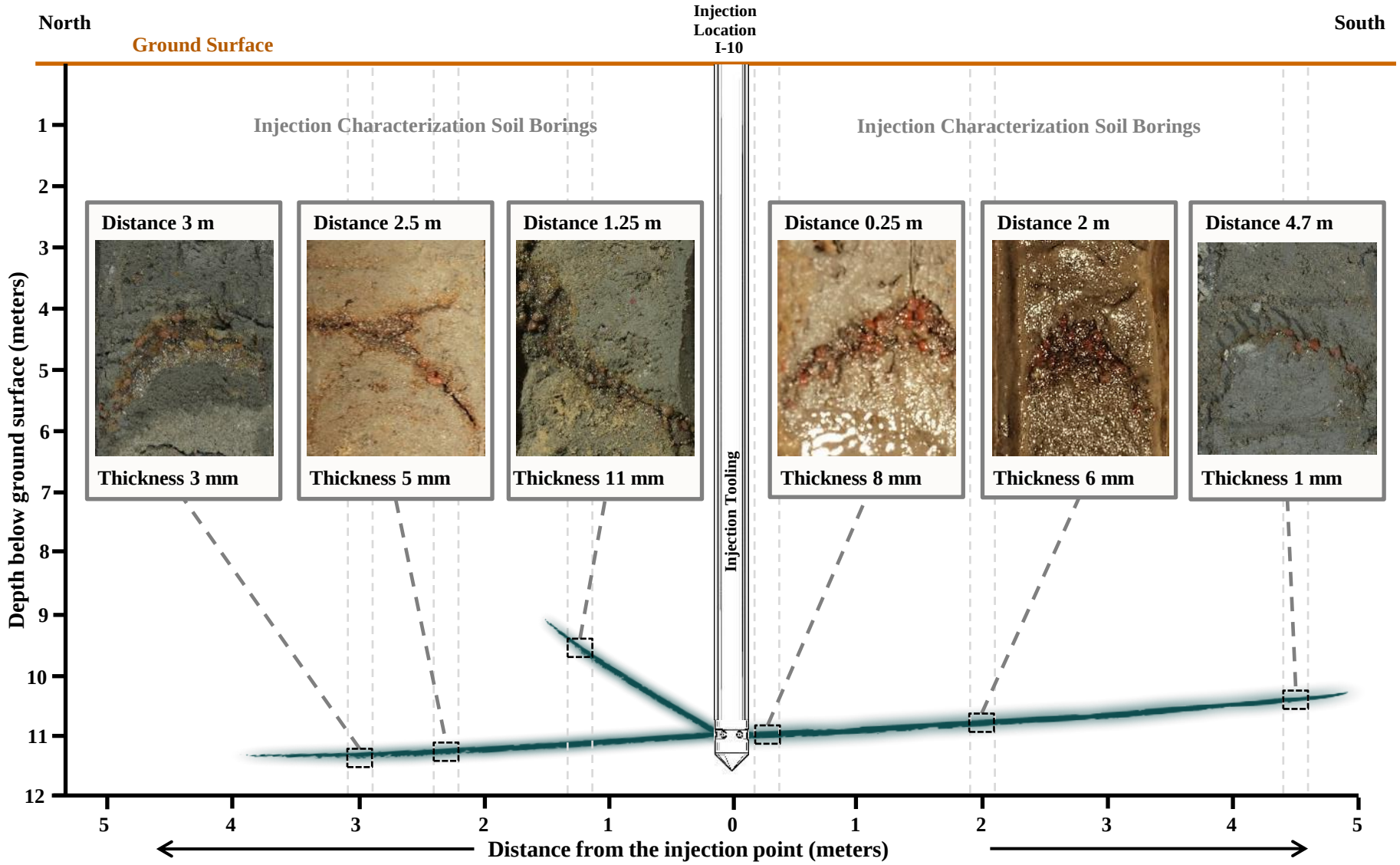

# Case Study: Distribution of Fractures – 3D Modeling

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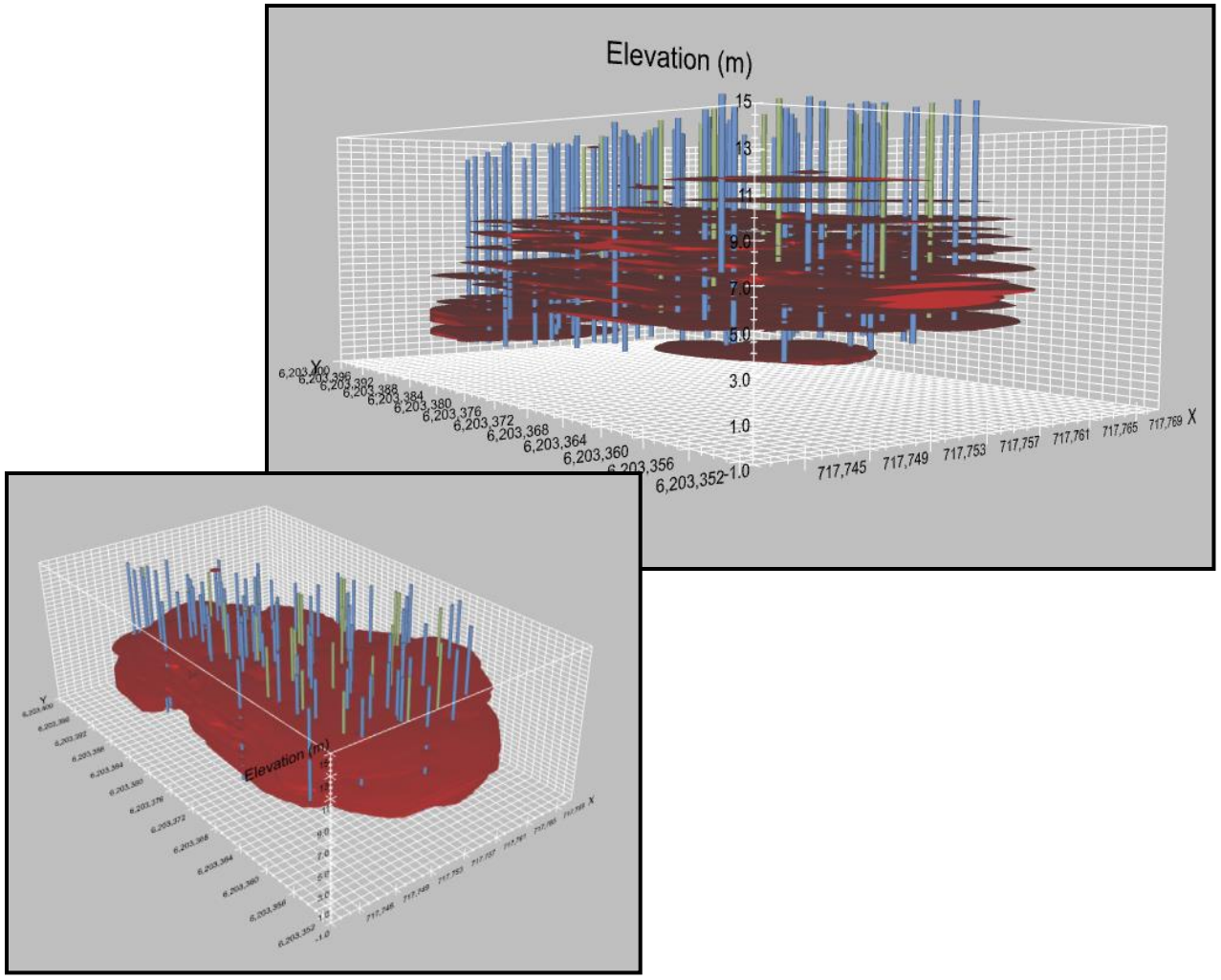
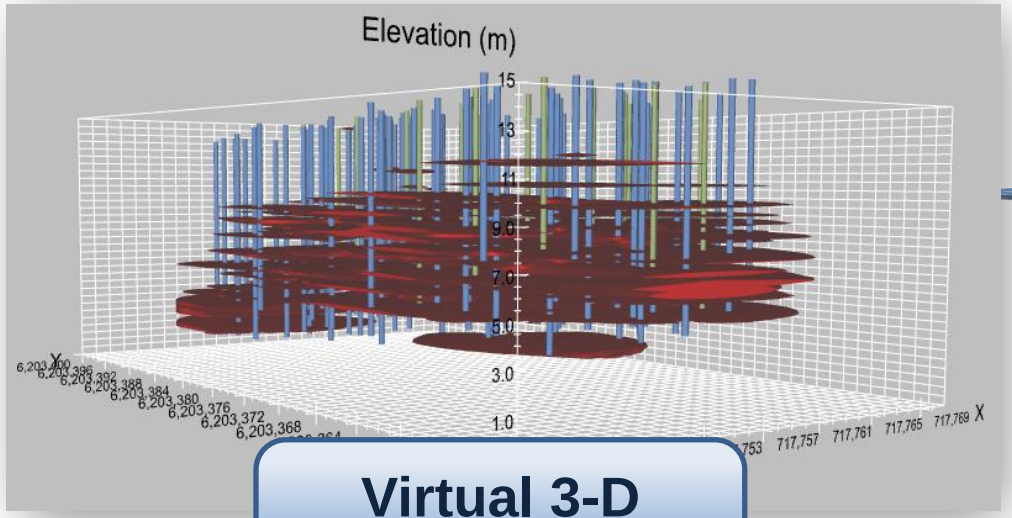
## METHODOLOGY

- 3D modeling (EVS software) was utilized to interpolate magnetic susceptibility (MS) readings.

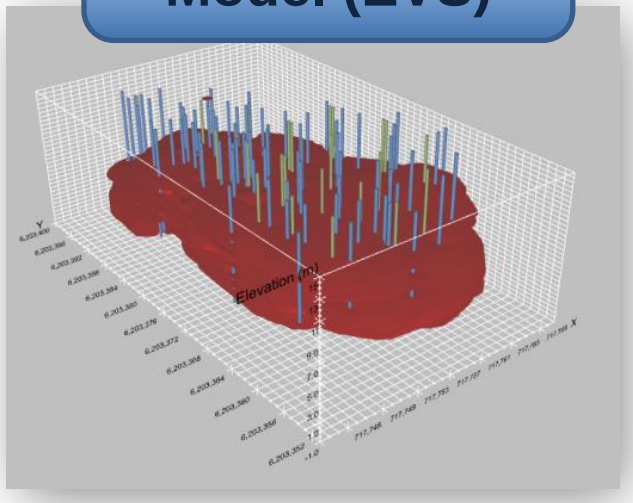
- Interpolated MS readings >1x10$^{-3}$ were generally co-located with visual identification of ZVI-filled fractures.



# Case Study – 3-D Print of Distribution




**Virtual 3-D Model (EVS)**



**3-D Printed Model**

# Case Study: Denmark – Treatment Results

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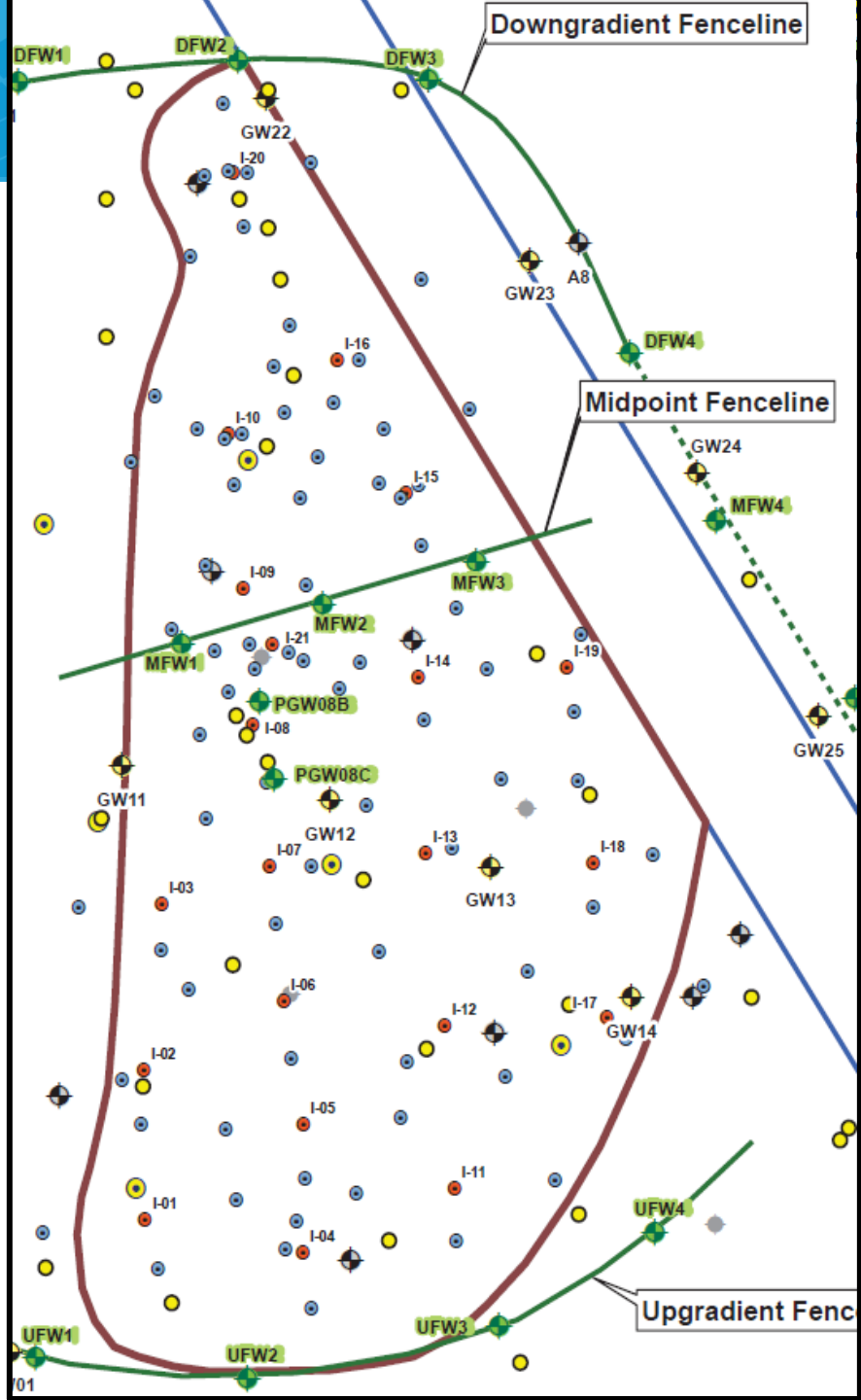
# Case Study – Performance Monitoring

## Demonstrated mZVI distribution, but what about VOC treatment?

- Groundwater sampling two times per year at ~ 13 well clusters (3 wells per cluster)
- Total VOC mass discharge analysis using transect method
- Soil sampling annually at ~14 locations
- Total VOC mass calculations using EVS



# VOCs in Soil – 6, 18, 30, & 42 months Post-Treatment Profiles

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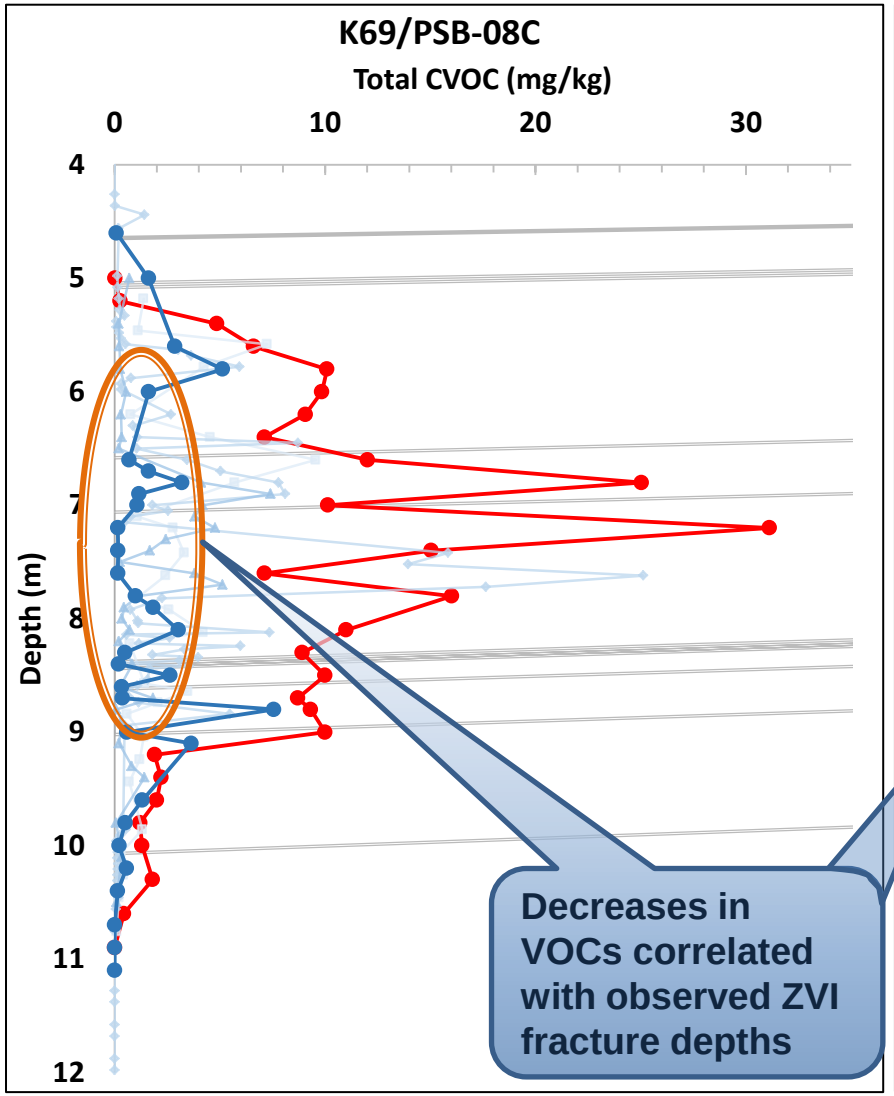
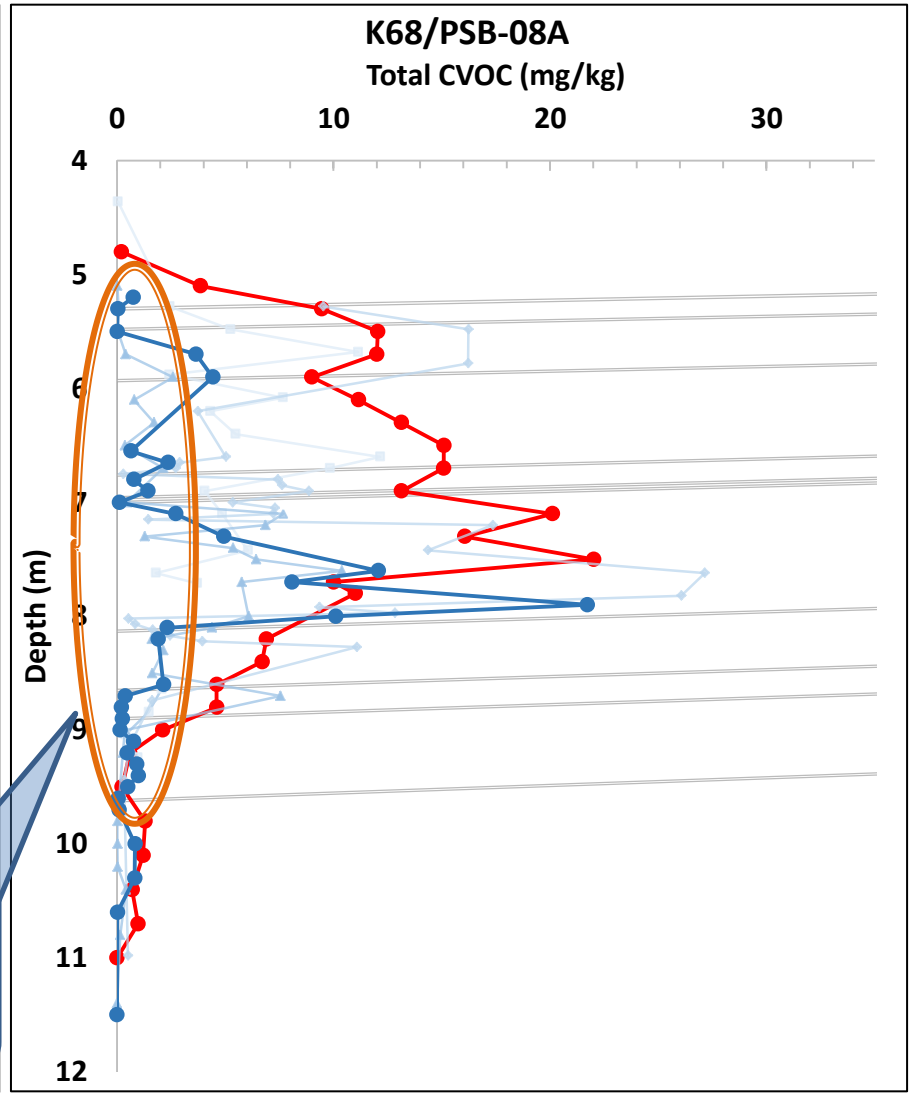
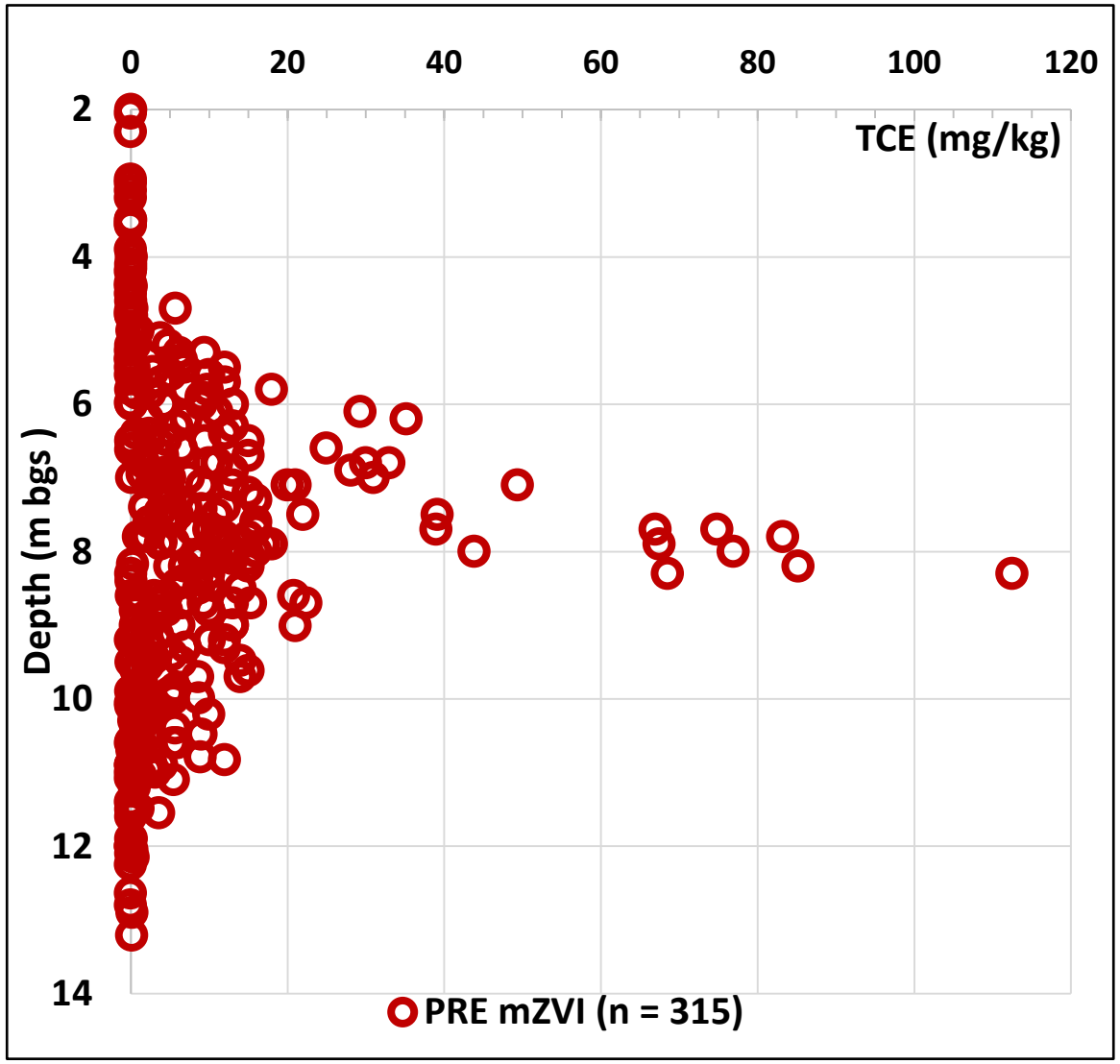


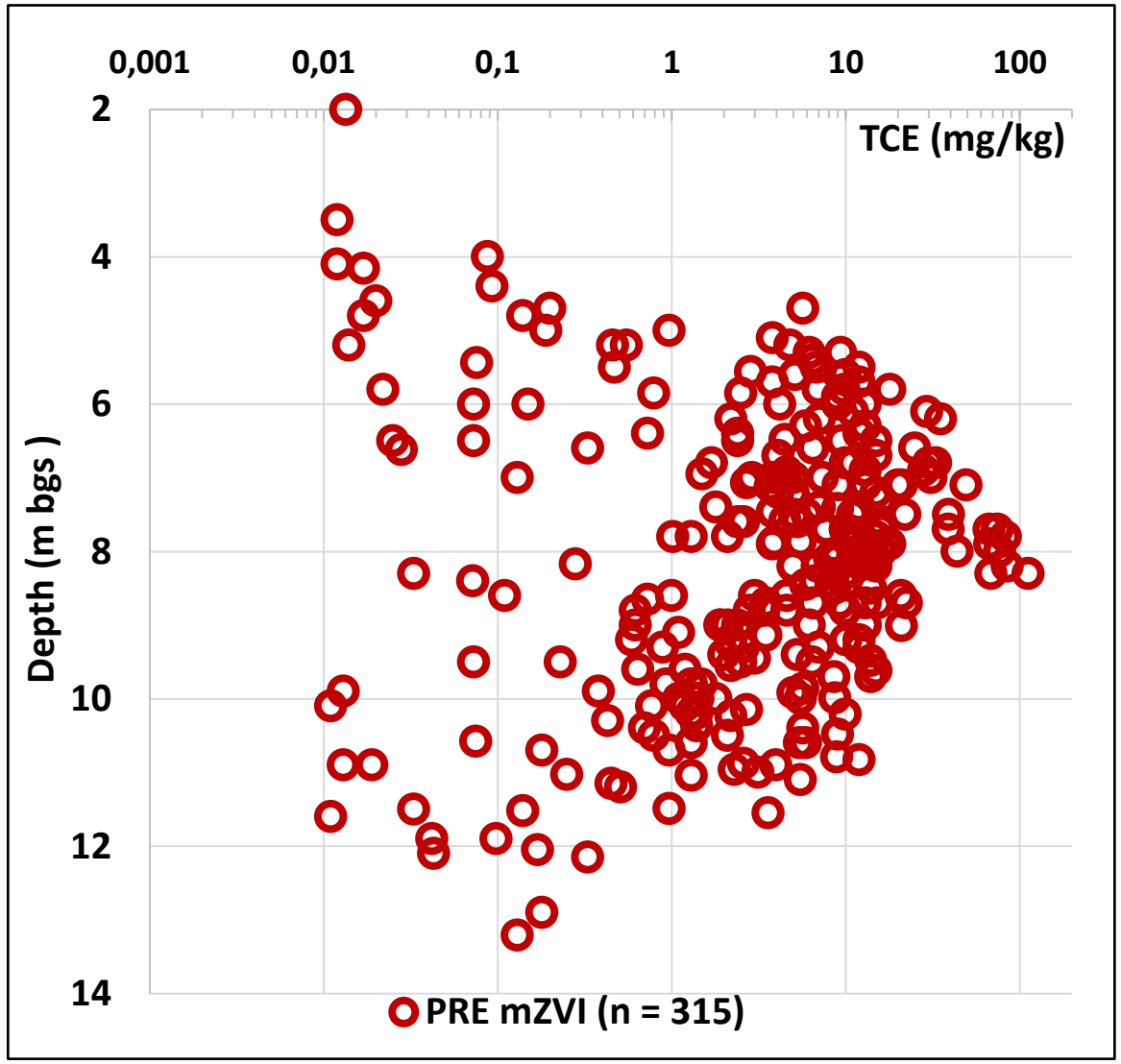




Decreases in VOCs correlated with observed ZVI fracture depths

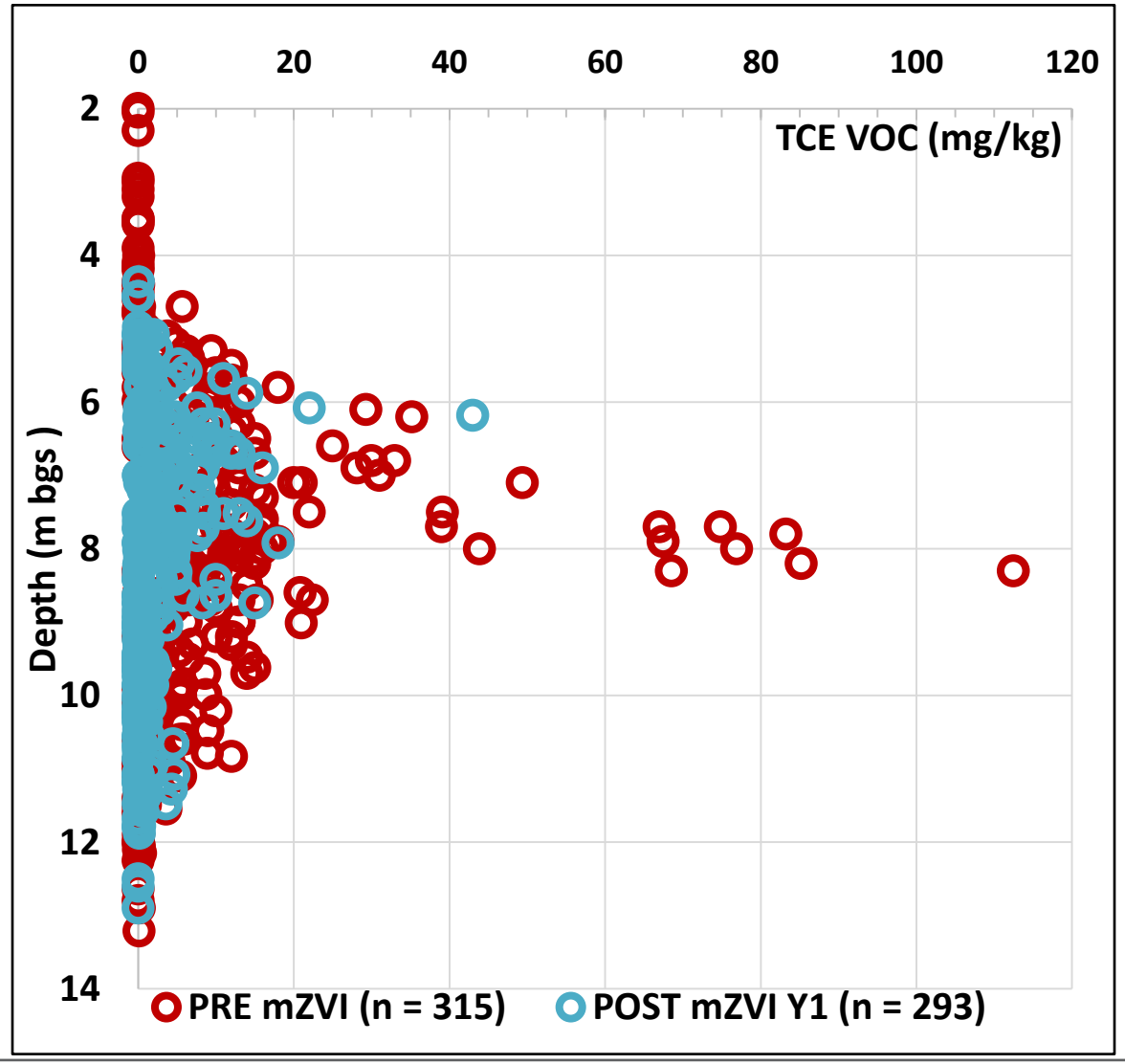
- ZVI Fractures (Year 4)
- K69 (Baseline)
- PSB-08C (Year 1)
- PSB-08C-Y2 (Year 2)
- PSB-08C-Y3 (Year 3)
- PSB-08C-Y4 (Year 4)

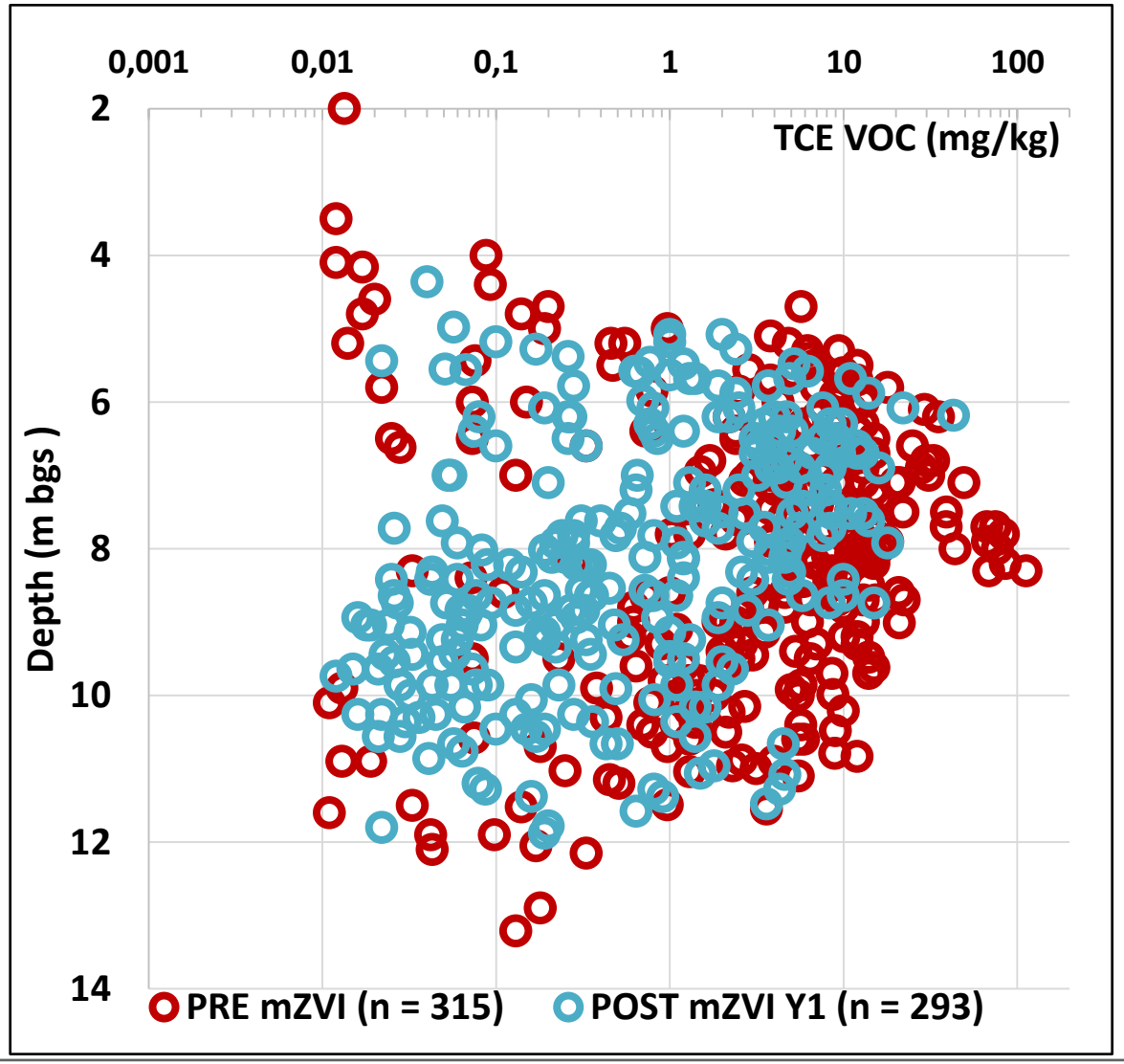
# TCE in Soil – Baseline



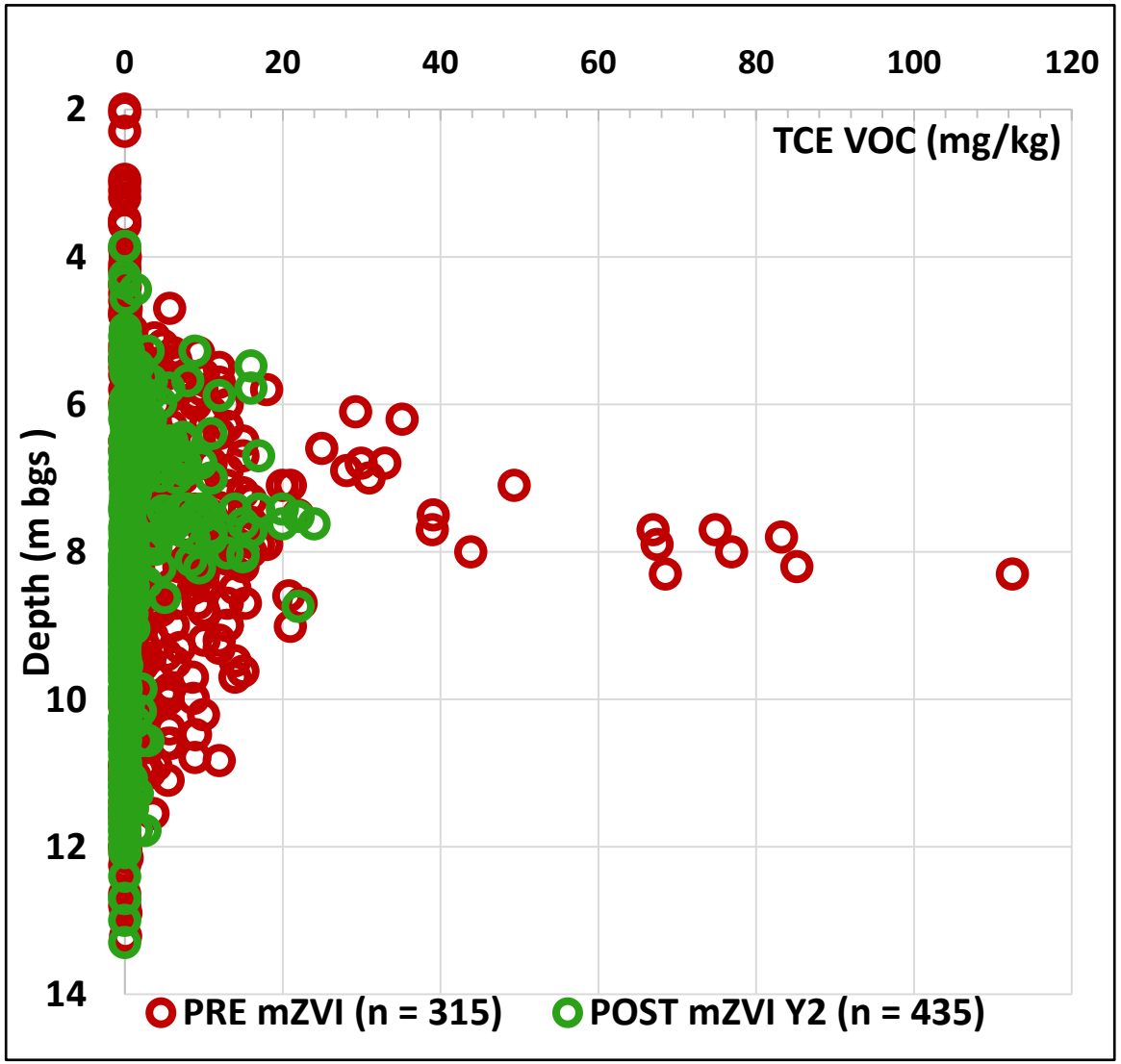



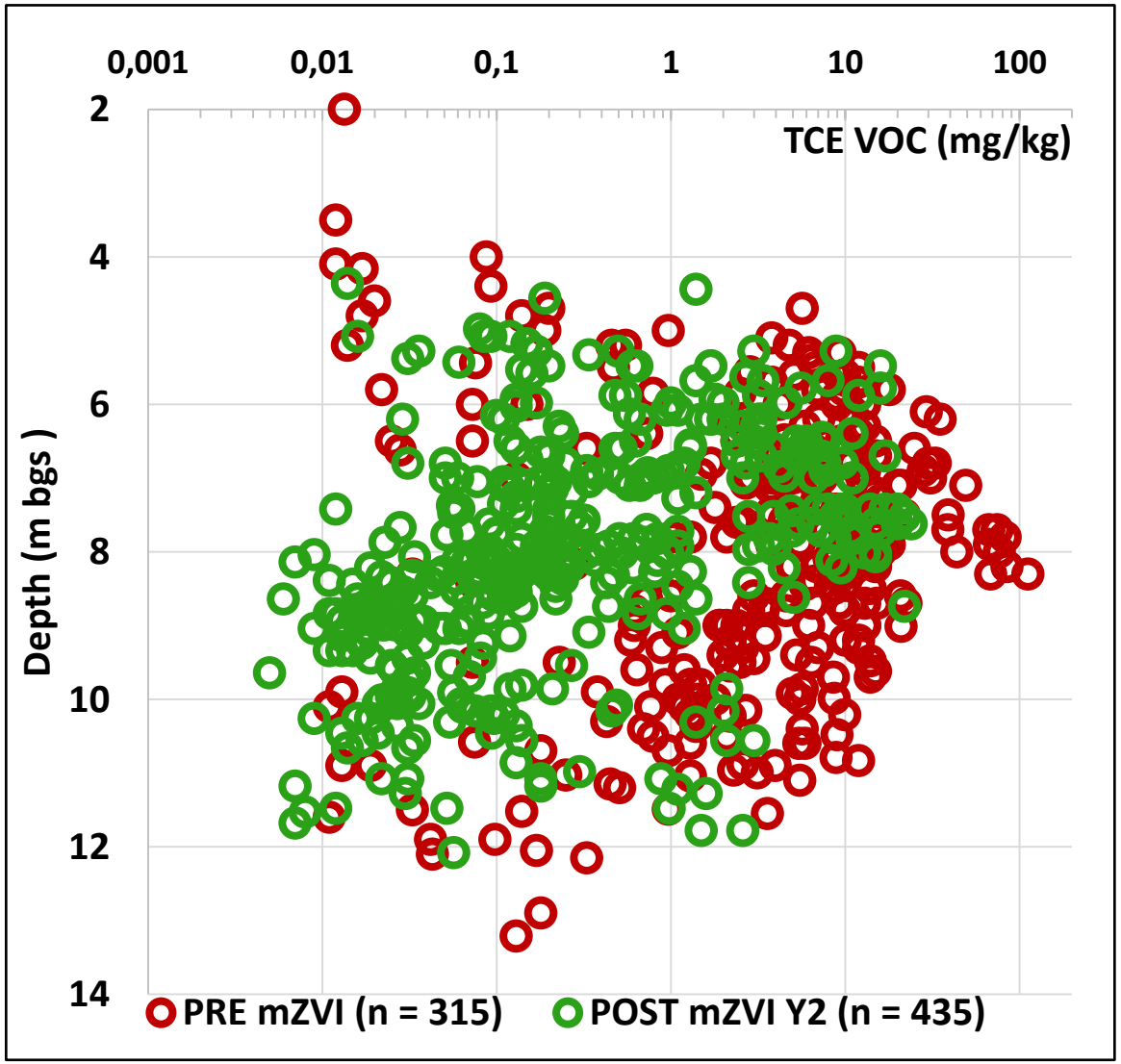
# TCE in Soil – Baseline vs Year 1



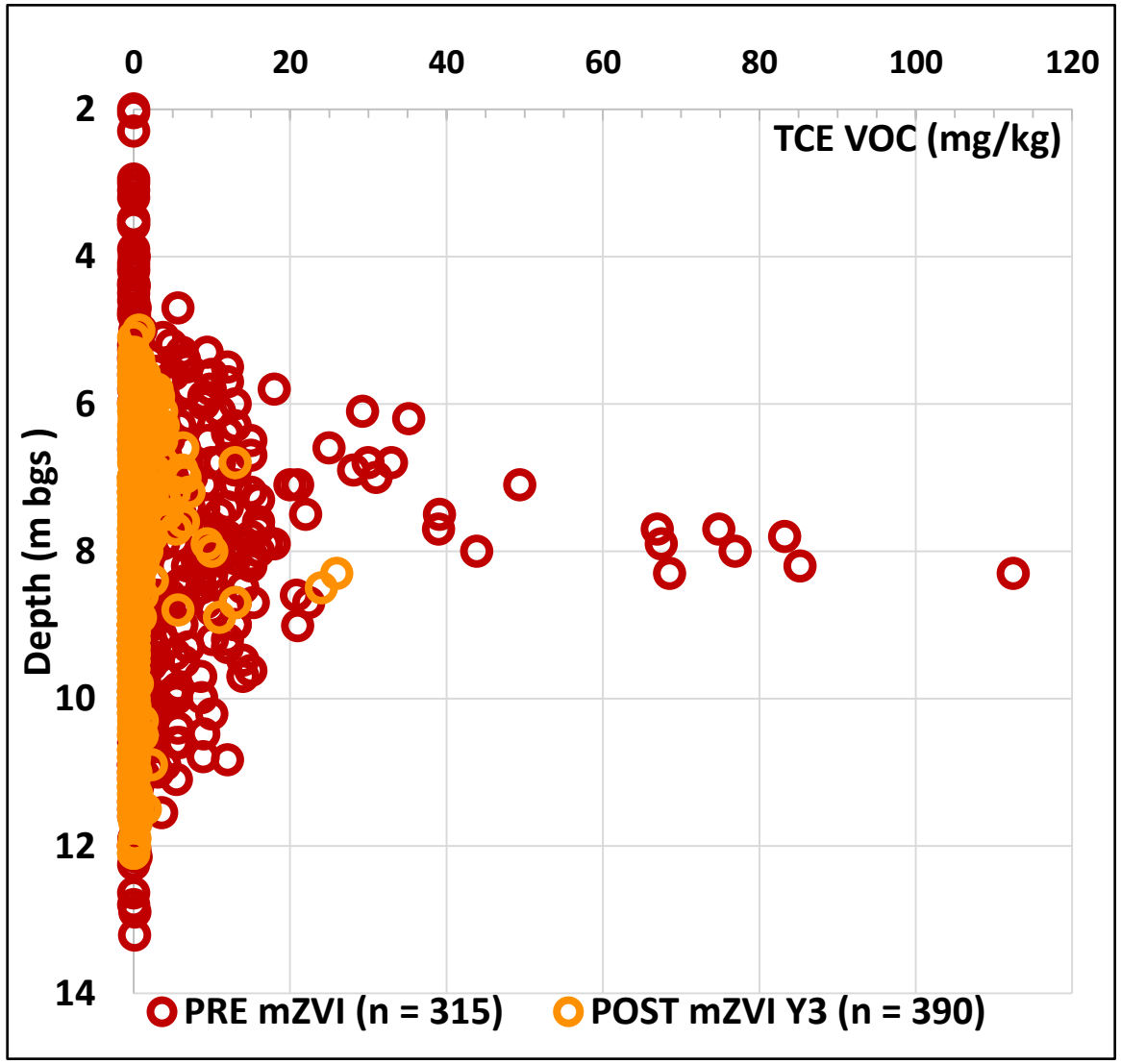



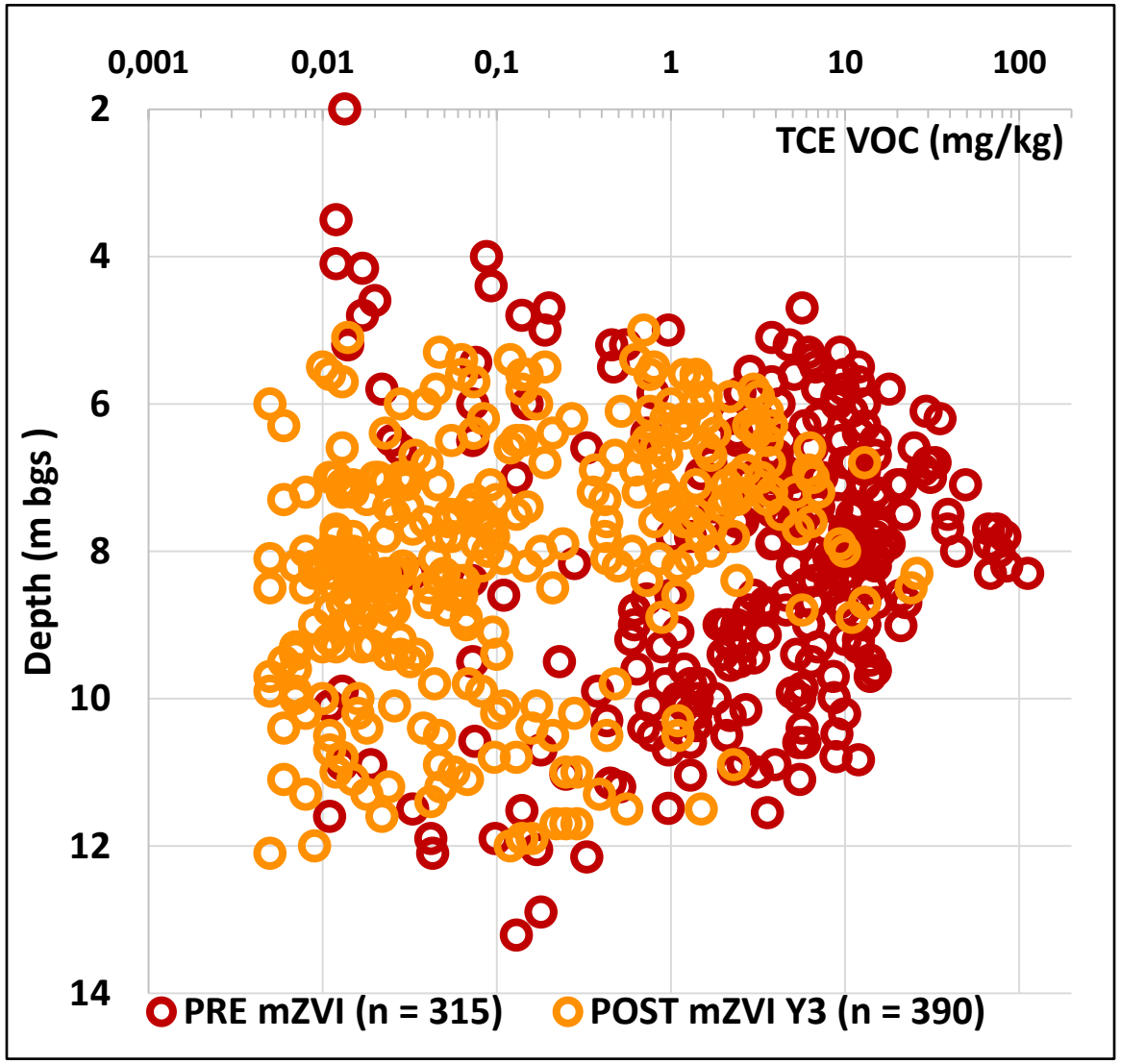
# TCE in Soil – Baseline vs. Year 2



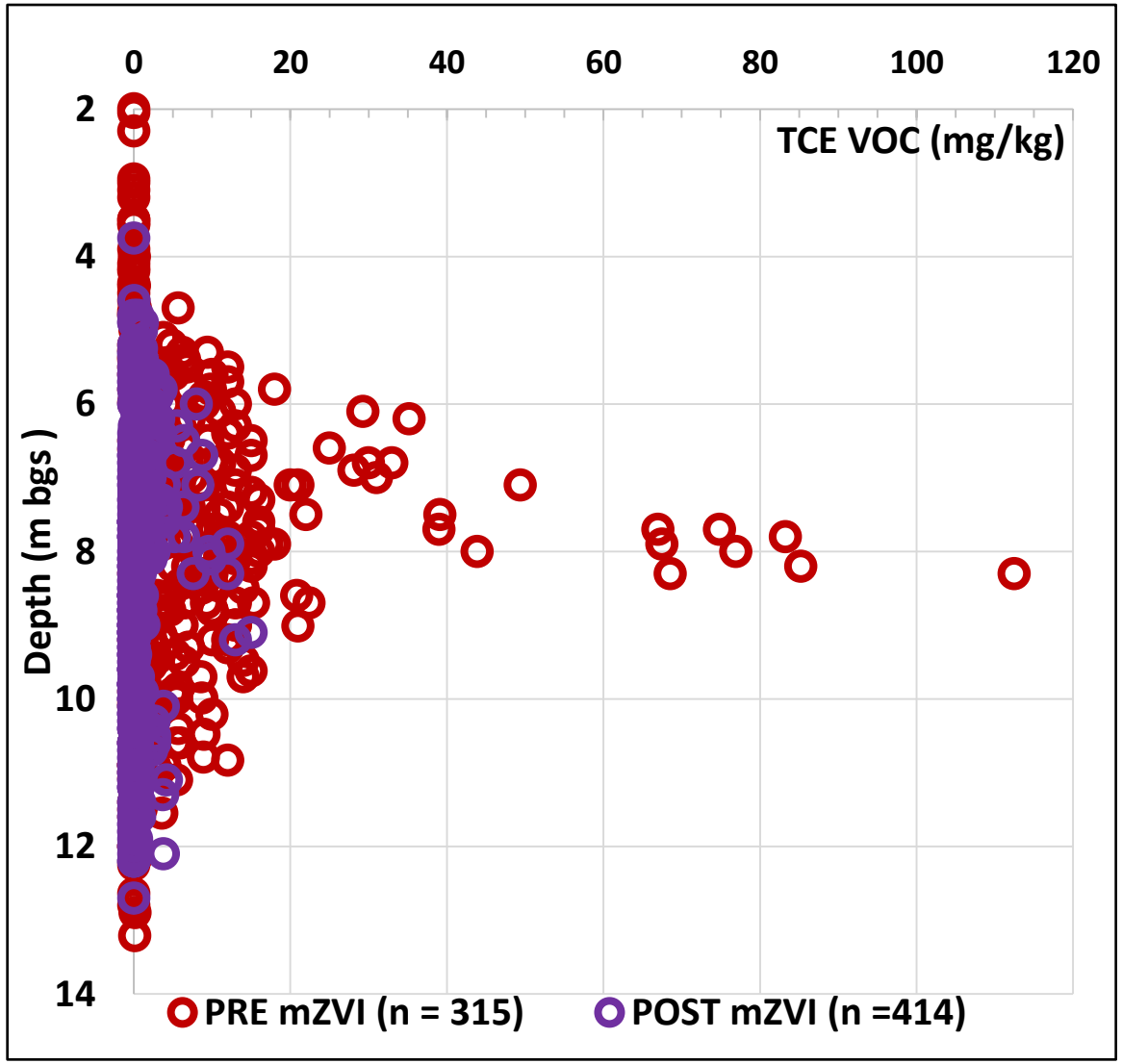



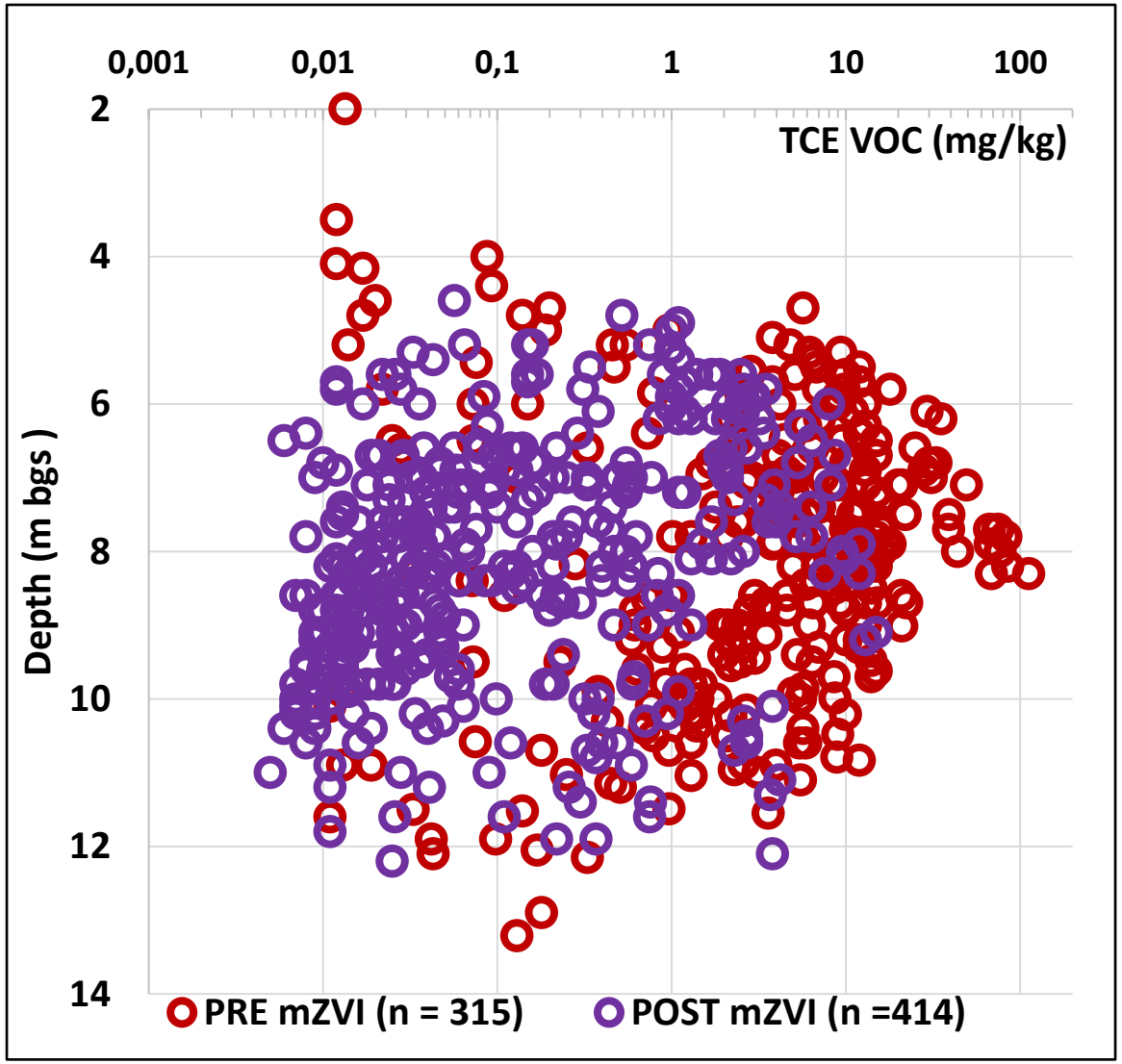
# TCE in Soil – Baseline vs. Year 3



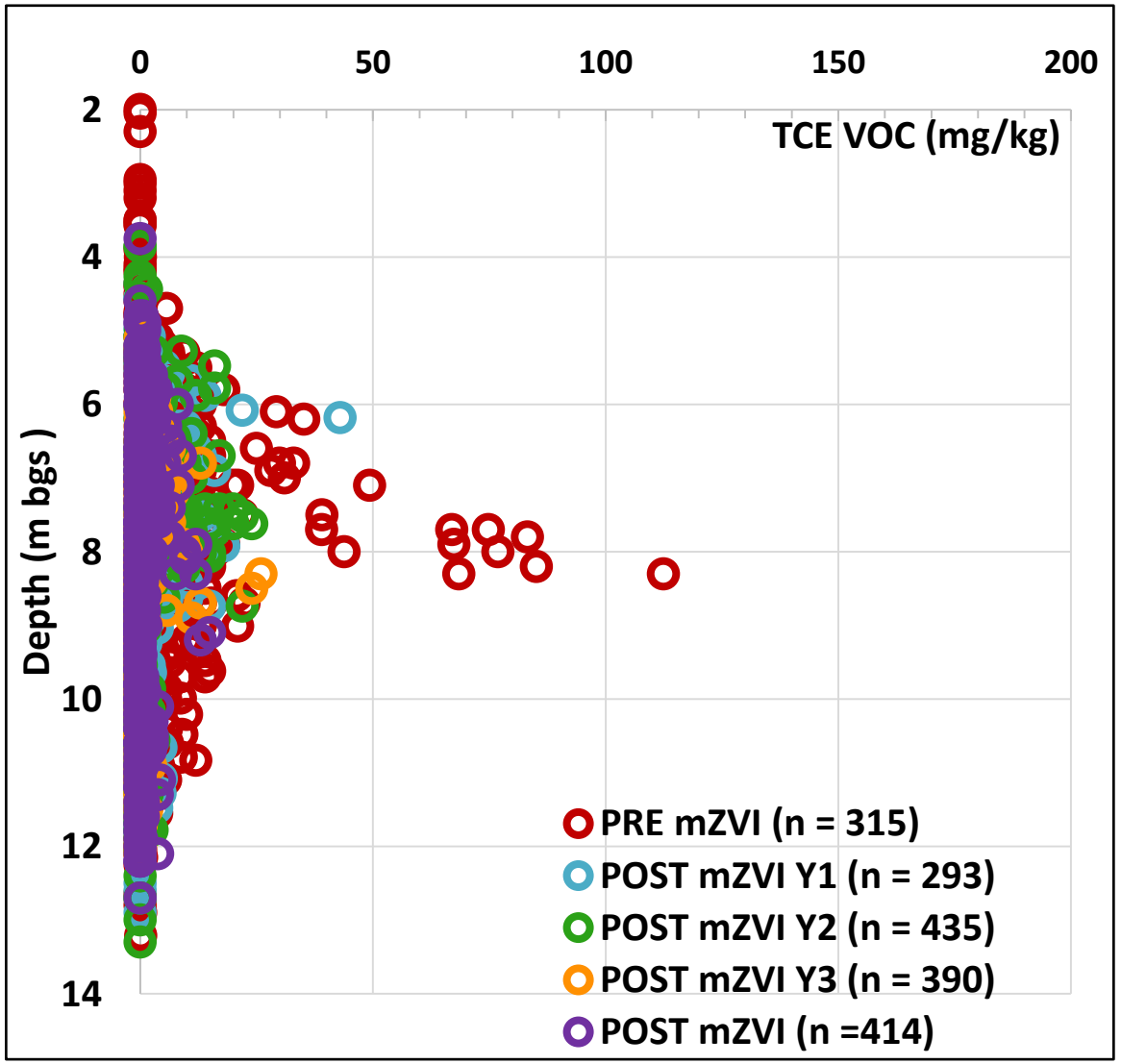



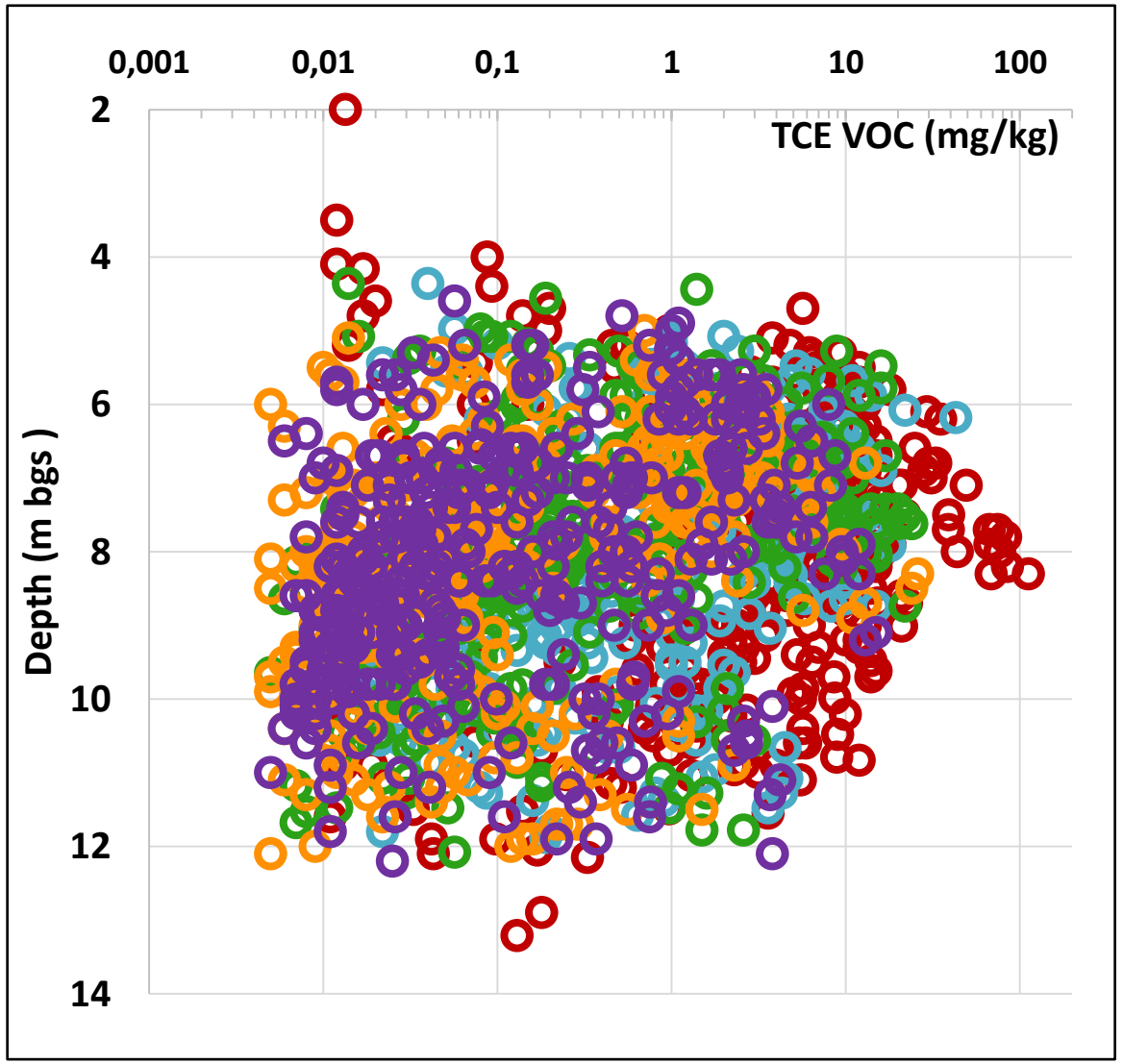
# TCE in Soil – Baseline Year 4



# TCE in Soil – Comparison All Years

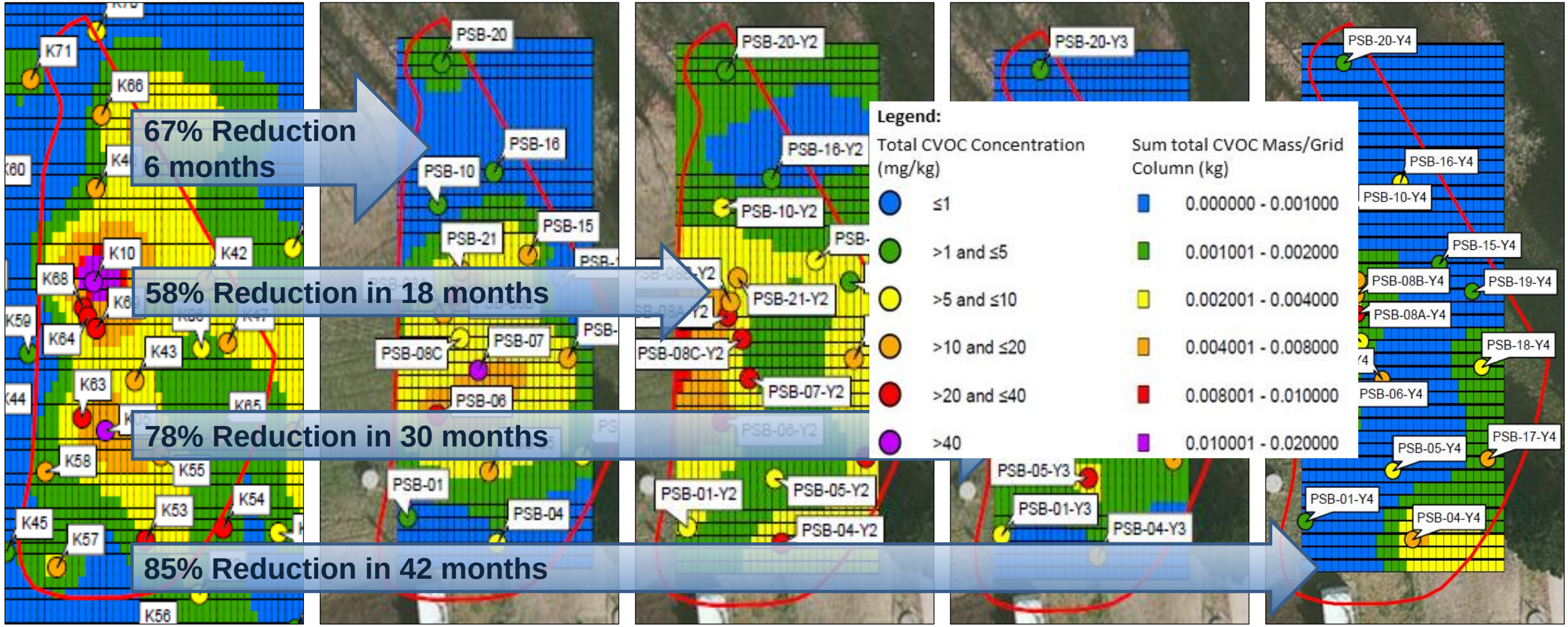


# Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

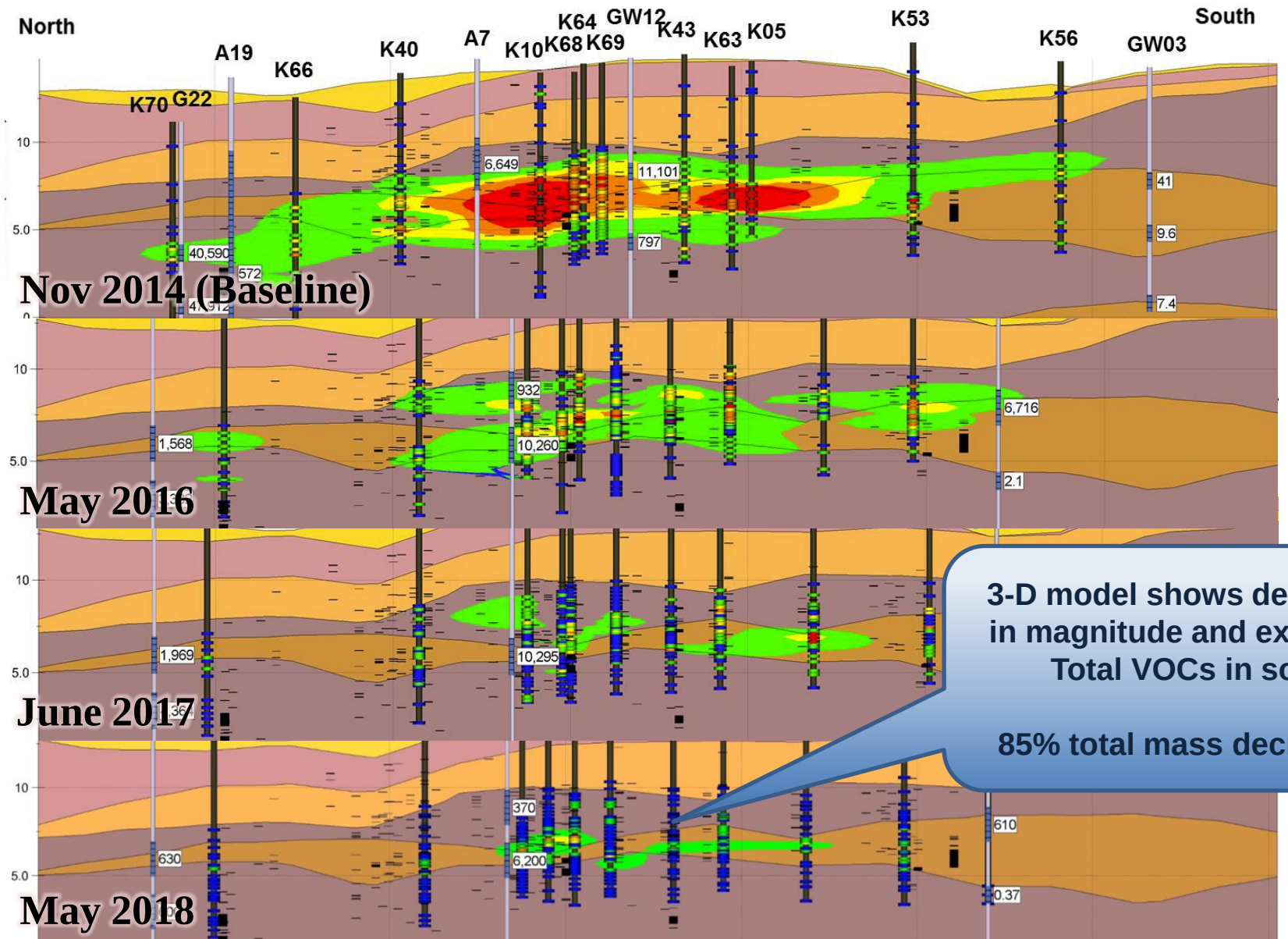
Geosyntec consultants

Nov 2014 (Baseline) | June 2015 | June 2016 | June 2017 | June 2018



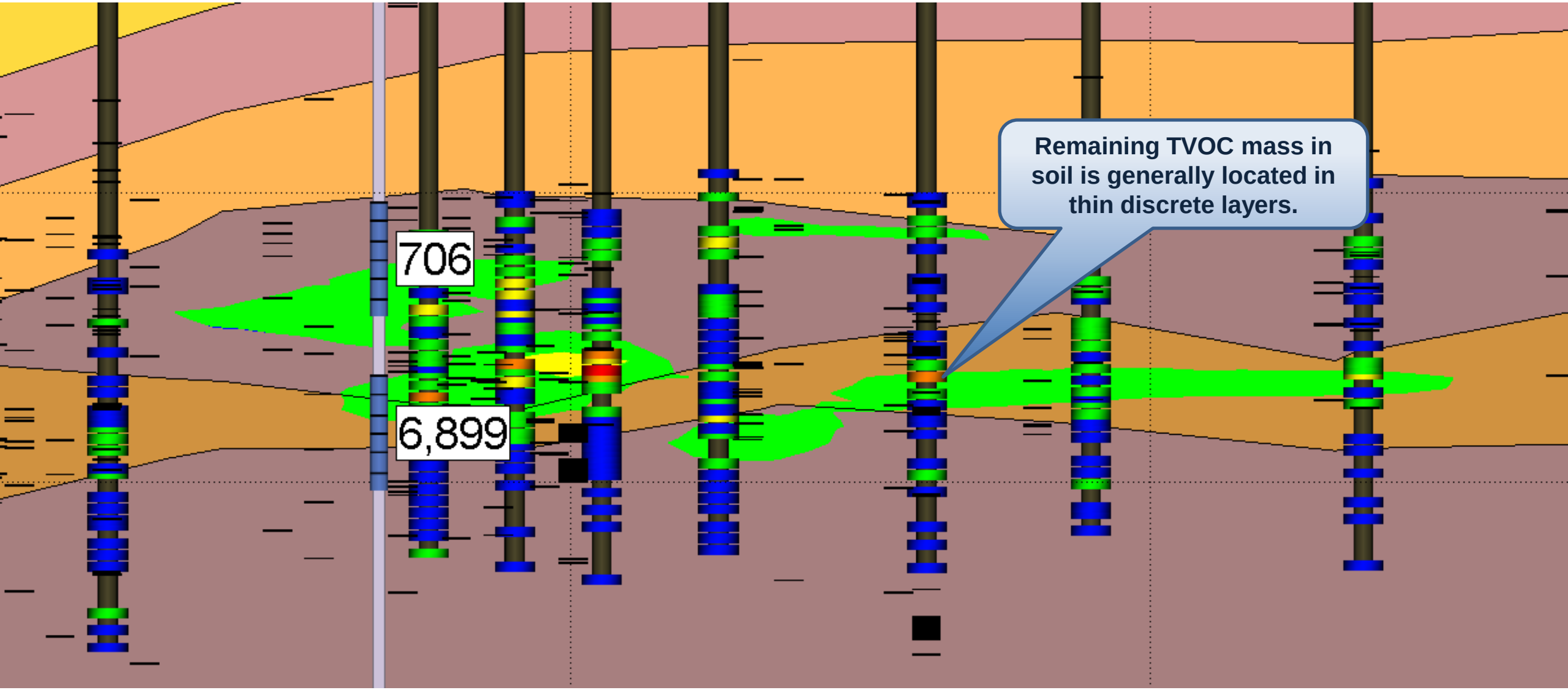
# Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

Geosyntec consultants



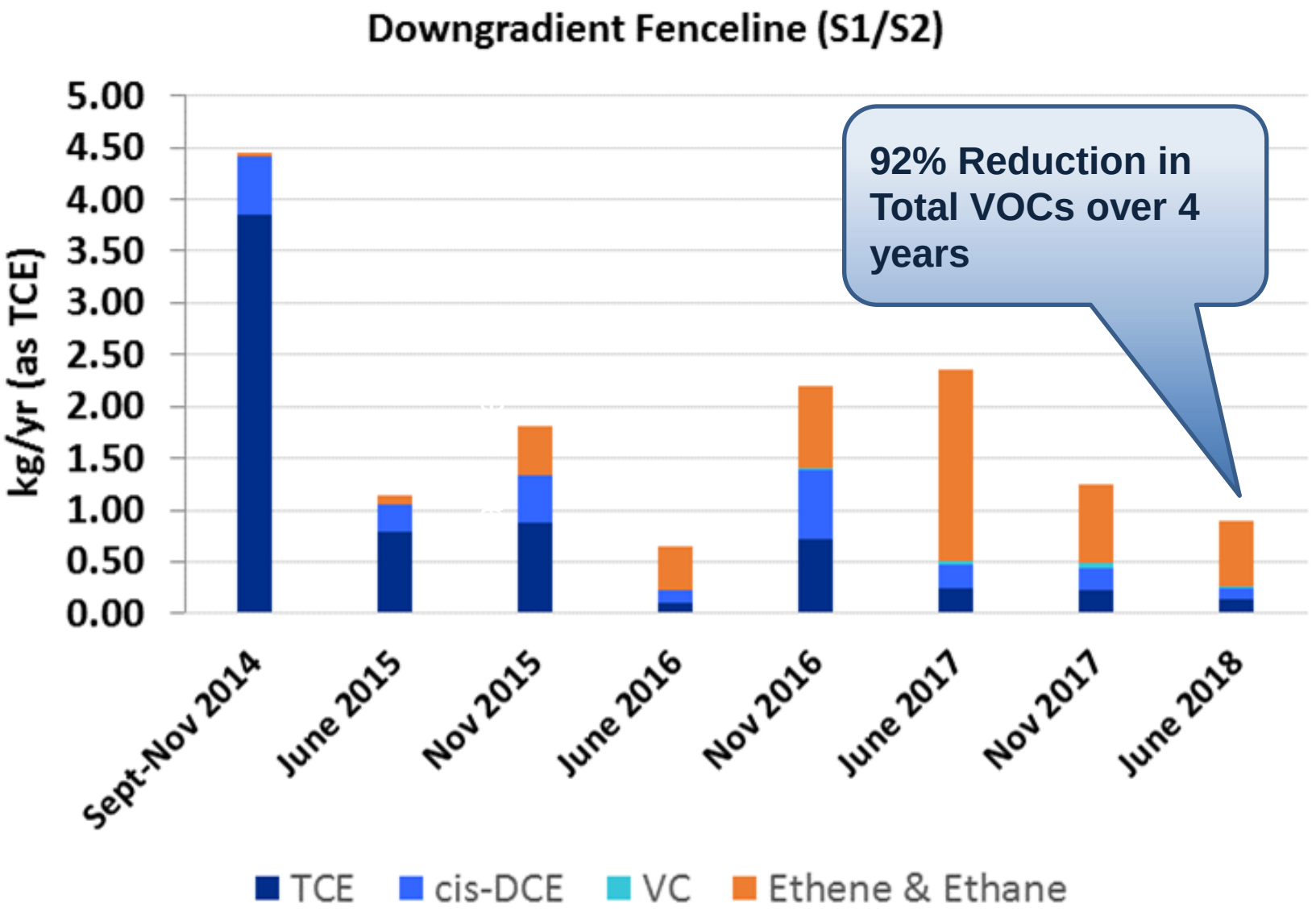
# Distribution of Total VOCs in Soil – 4 years Post-Treatment

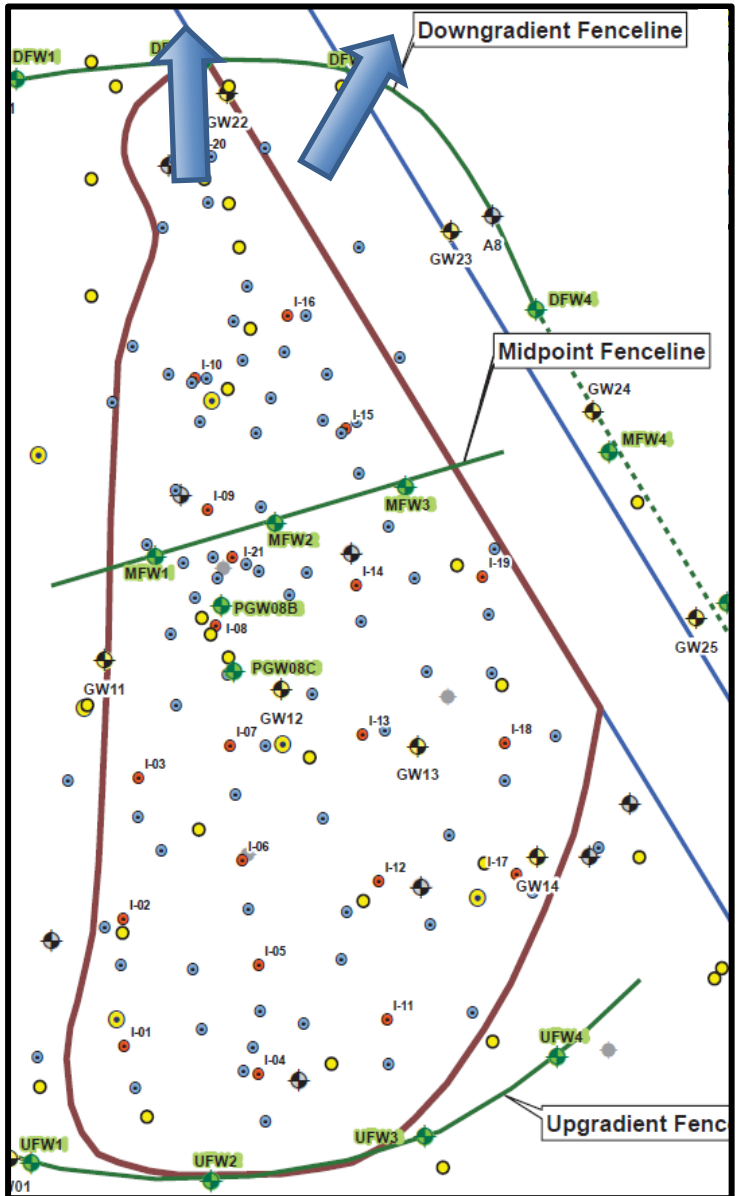
Geosyntec consultants



# Mass Discharge VOCs in Groundwater from TTA

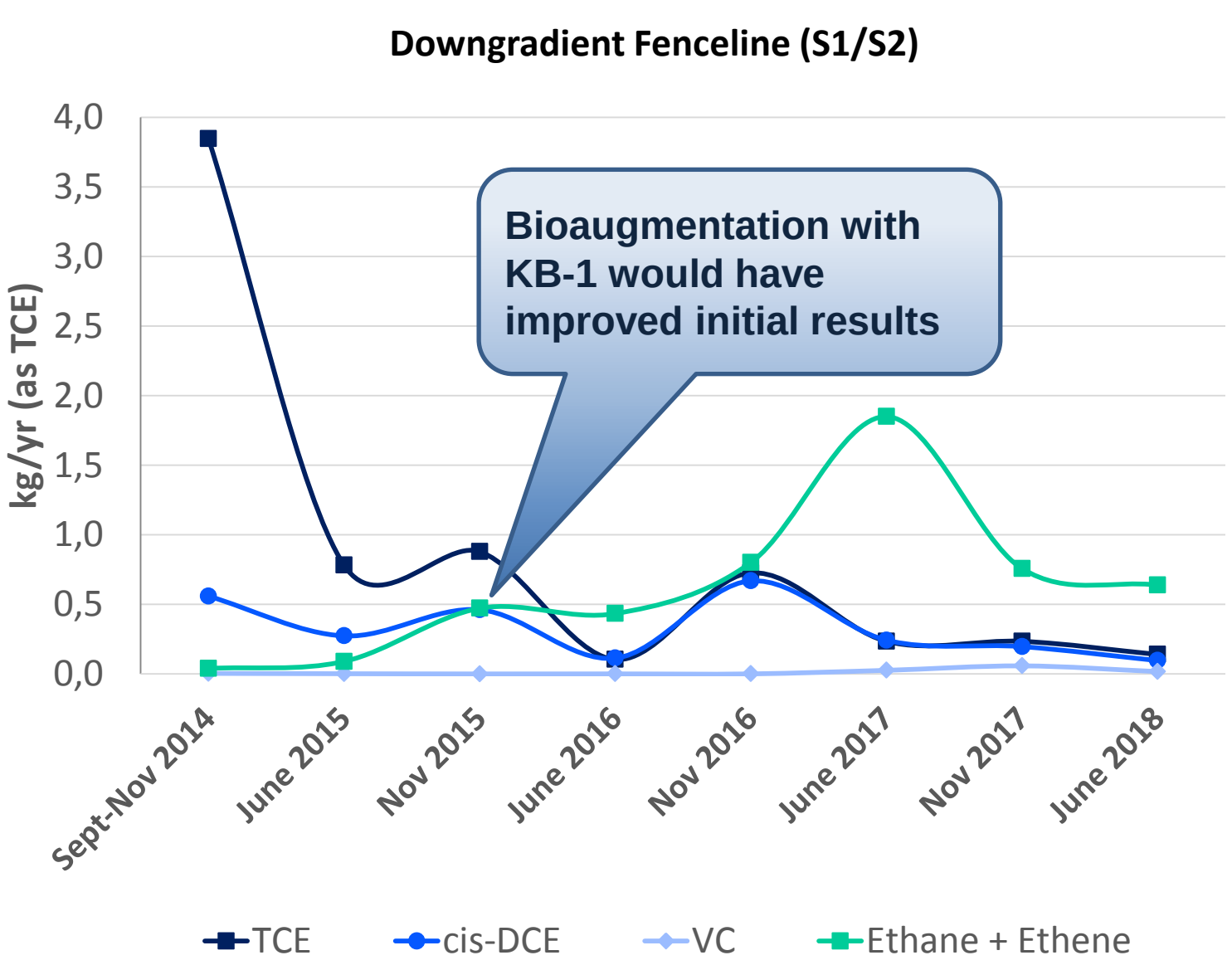
Geosyntec consultants

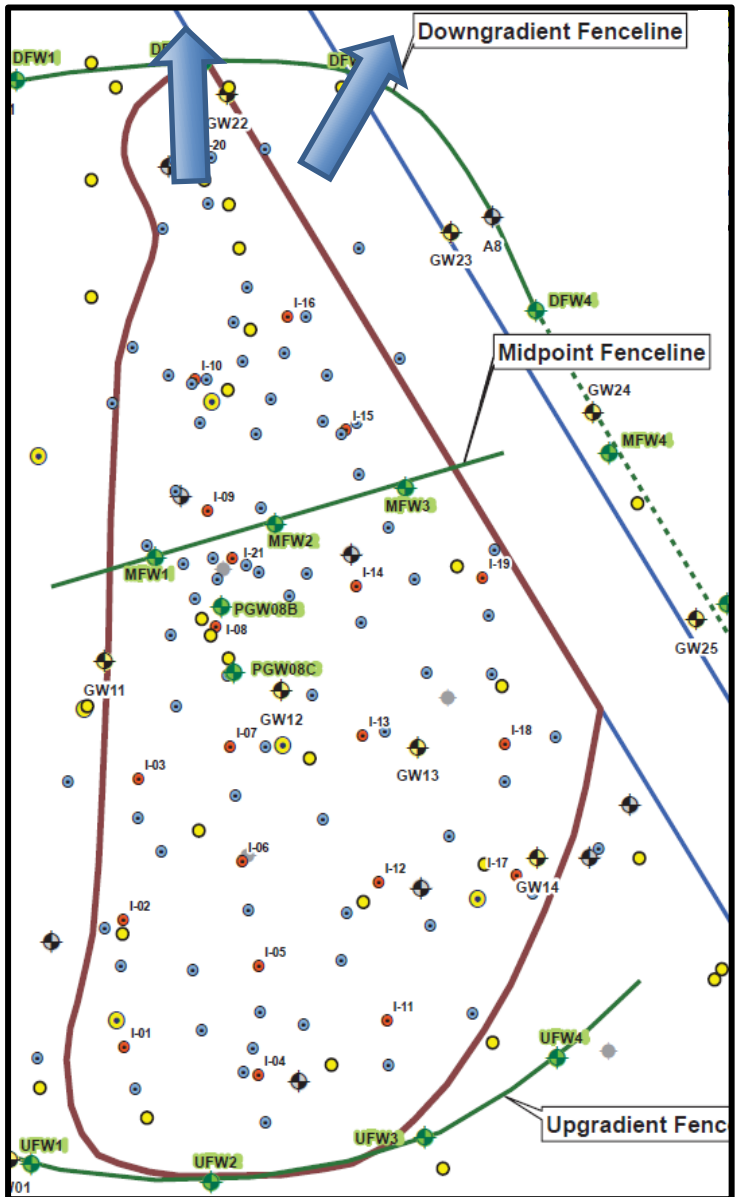


# Mass Discharge VOCs in Groundwater from TTA

Geosyntec consultants



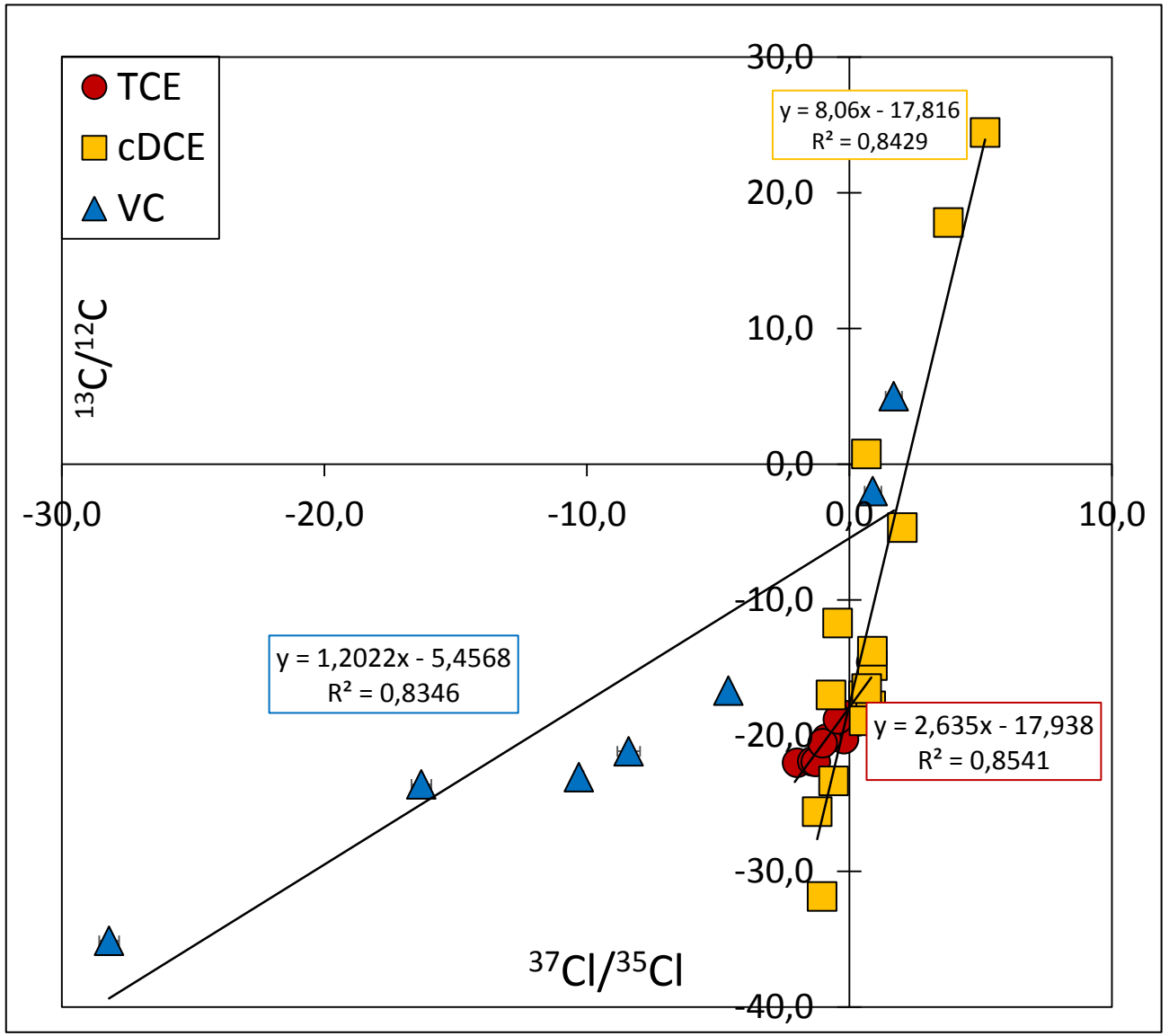



# Compound Specific Isotope Analysis

Geosyntec consultants

**$^{13}C/^{12}C$ vs $^{37}Cl/^{35}Cl$ duel isotope ratios**

- **Observations**
  - Dual C-Cl isotope slopes reflect ongoing degradation pathways independent of concentration
  - TCE, cDCE, and VC all plot along linear trendlines & suggest distinct degradation pathways ($R2 \geq 0.83$)
- **cDCE**
  - C-Cl isotope slope for cDCE (**8.06)** falls between two ranges of literature values for anaerobic biodegradation (**10.8 to 14.88**) and ZVI based abiotic degradation (**5.0** and **3.2**) of cDCE (Abe et al., 2009; Audí-Miró et al., 2013; 2015).
- **Observations:**
  - Ongoing mixture of biotic and abiotic processes resulting in simultaneous production and degradation of compounds
- **Limitations**
  - Samples represent evolution of impacted groundwater as it travels into, though, and out of a heterogenous source zone and treatment area.
  - Single site-wide sampling event
    - Additional sampling rounds will better elucidate trends

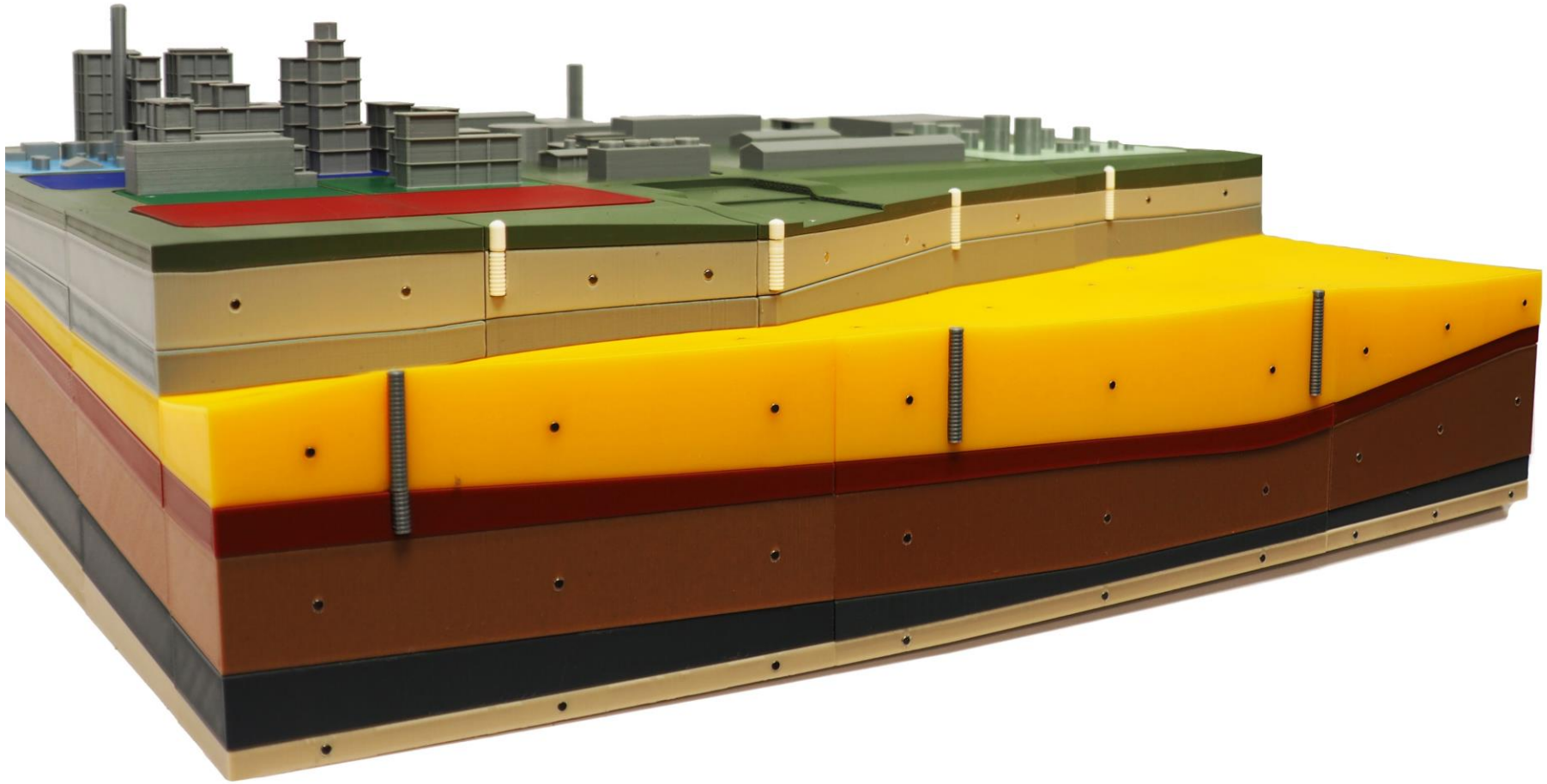


# Case Study Conclusions – DPT Jet Injection in Denmark

Geosyntec consultants

- **Distribution of mZVI with DPT Jet Injection demonstrated be extremely effective in highly fractured clay till.**
- **Treatment results in soil and groundwater over 4 years show effective treatment in clay till using DPT Jet Injection.**
  - Total TCE mass in soil decreased by 94% after 4 years.
  - Total VOC mass in soil decreased by 85% after 4 years.
  - Total VOC mass discharge in groundwater decreased by 92% after 4 years.
  - Increasing ethane/ethene concentrations demonstrate complete degradation (max. ethane conc. in 2018 = ~7 mg/L).

# Thank you!

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