In-Situ Thermal Treatment of Fractured Rock

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2014 remediation technologies symposium

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About TerraTherm, Inc.


TCH at a recently completed site in USEPA Reg. 2

- TerraTherm, a US-based company, is the only thermal vendor offering all 3 of the major methods of subsurface heating, TCH, SEE and ERH/ET-DSP™.
- At > 35 consecutive projects since 2002 on four continents, TerraTherm has met all remedial goals upon completion.

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TerraTherm – What We Do

Sites with environmental liability and NAPL source zones

Pioneer Midler Ave. Site, Syracuse, NY

Cleanup Standard (mg/kg)
PCE < 5.60
TCE < 2.80
VC < 0.80
t-1,2-DCE < 1.20
TVOC <10.40
ALL ACHIEVED

Largest of the 3 Target Treatment Zones (TTZs)

Home Improvement Store built adjacent to the TTZ

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Contaminant Mass Removal

Mass removal from thermal sites (by TerraTherm staff):

>1,340,000 kg contaminants:

- Chlorinated solvents
- Creosote/PAHs
- Coal tar
- Oils
- PCBs
- Dioxins

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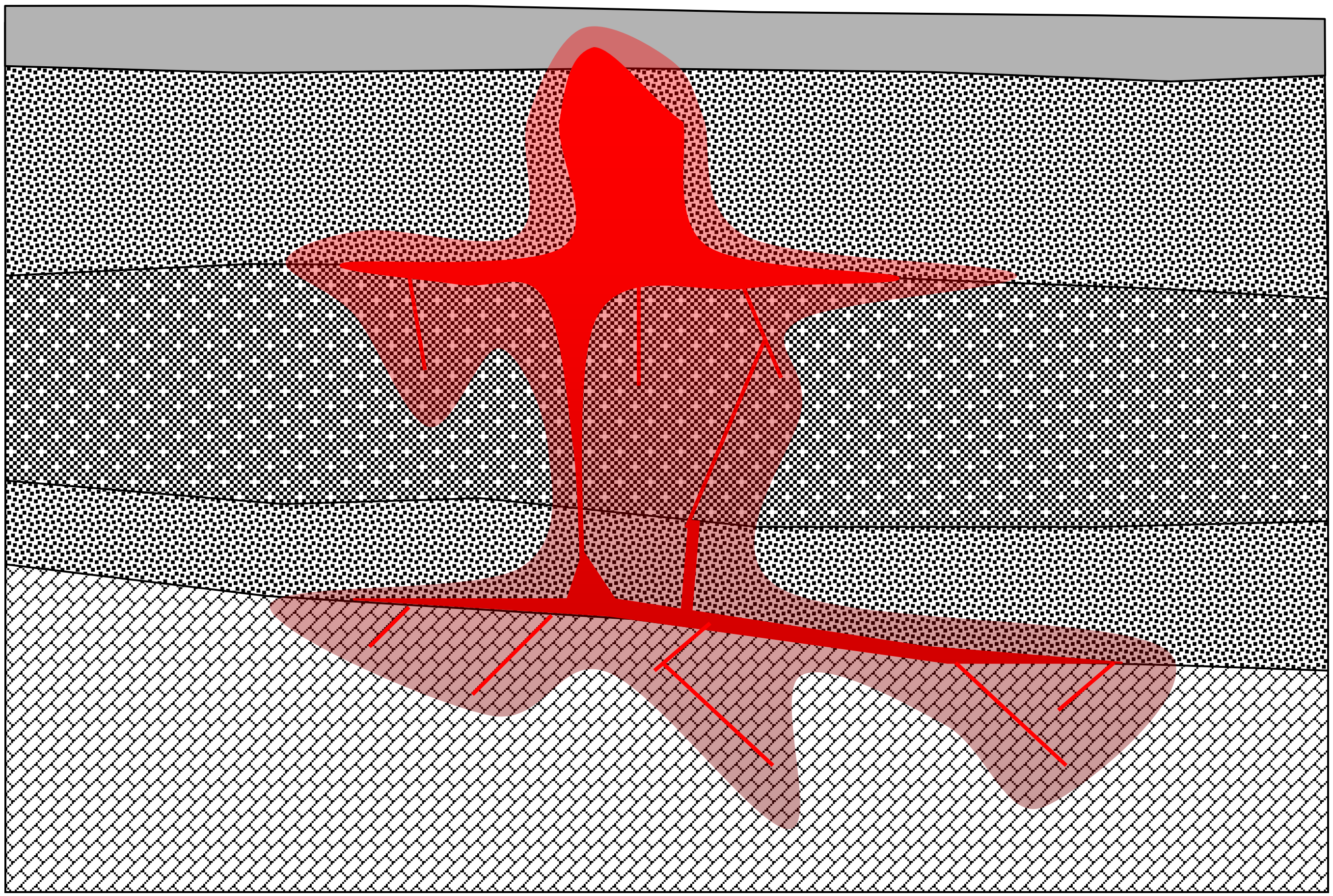
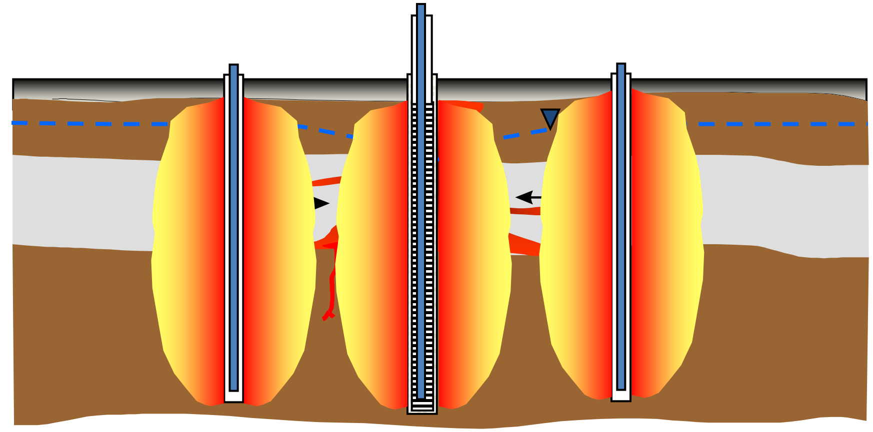
Example
Source Area DNAPL and VOC Distribution

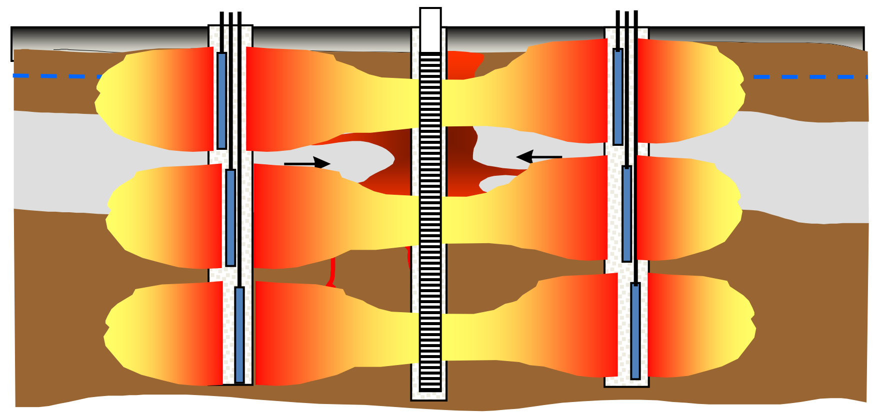


Heating Methods

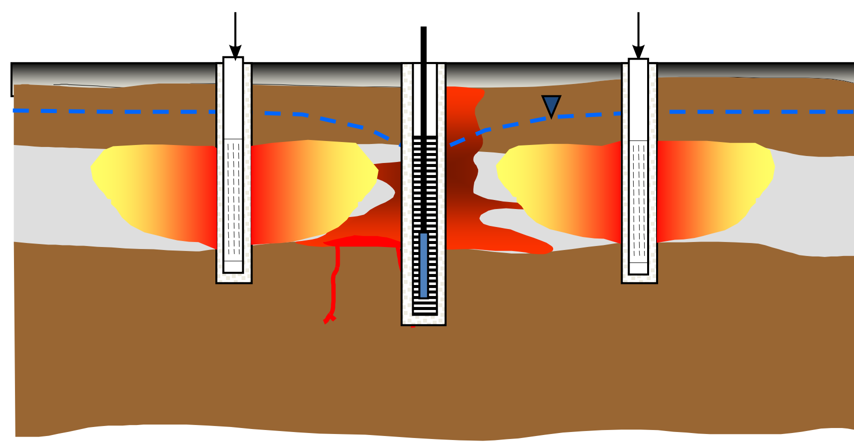
Thermal Conduction Heating* (TCH)/In Situ Thermal Desorption* (ISTD) - Heating governed by **thermal conductivity**



ElectroThermal-Dynamic Stripping Process™* (ET-DSP™)/Electrical Resistance Heating (ERH) - Heating governed by **electrical conductivity**



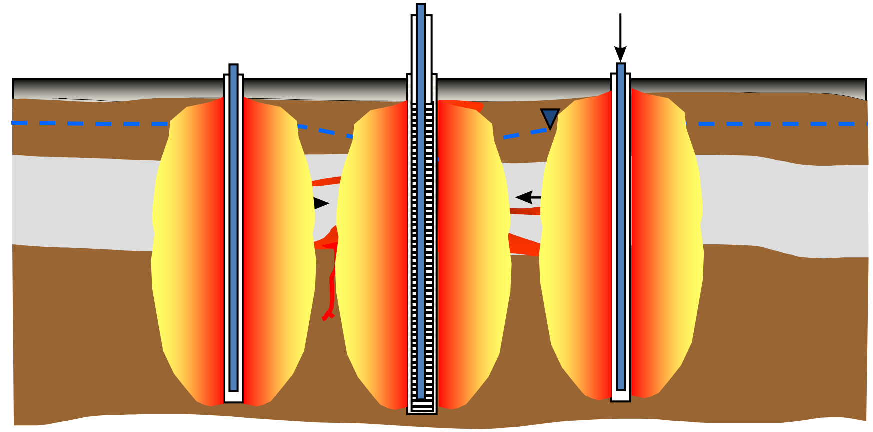
Steam-Enhanced Extraction* (SEE) - Heating governed by **hydraulic conductivity**



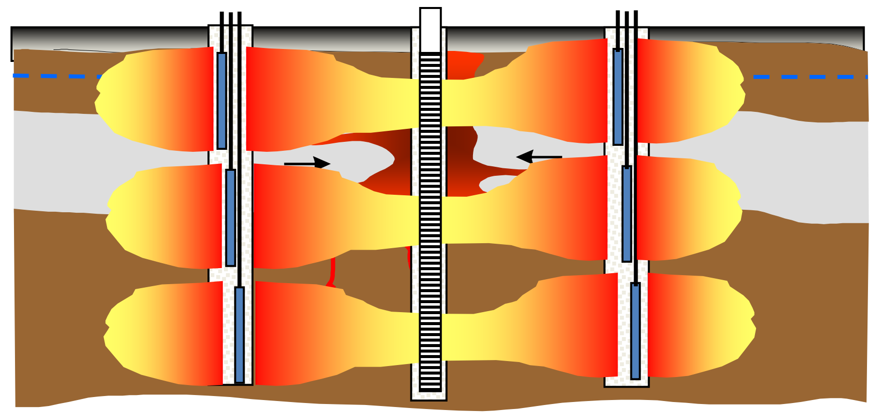
*Offered by TerraTherm

Applicability

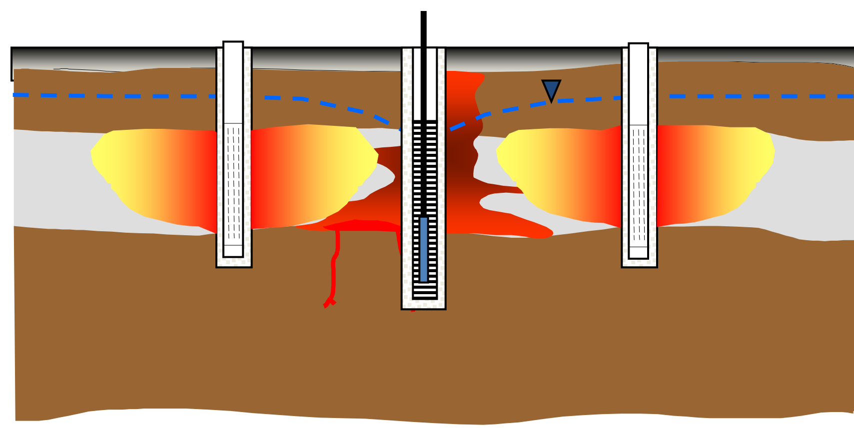
TCH* - Heating governed by **thermal conductivity** (*f*~3); Wide range of target temperatures; Low to moderate permeability settings



ERH* - Heating governed by **electrical conductivity** (*f*~200); ≤ B.P. of water; Low to moderate permeability settings

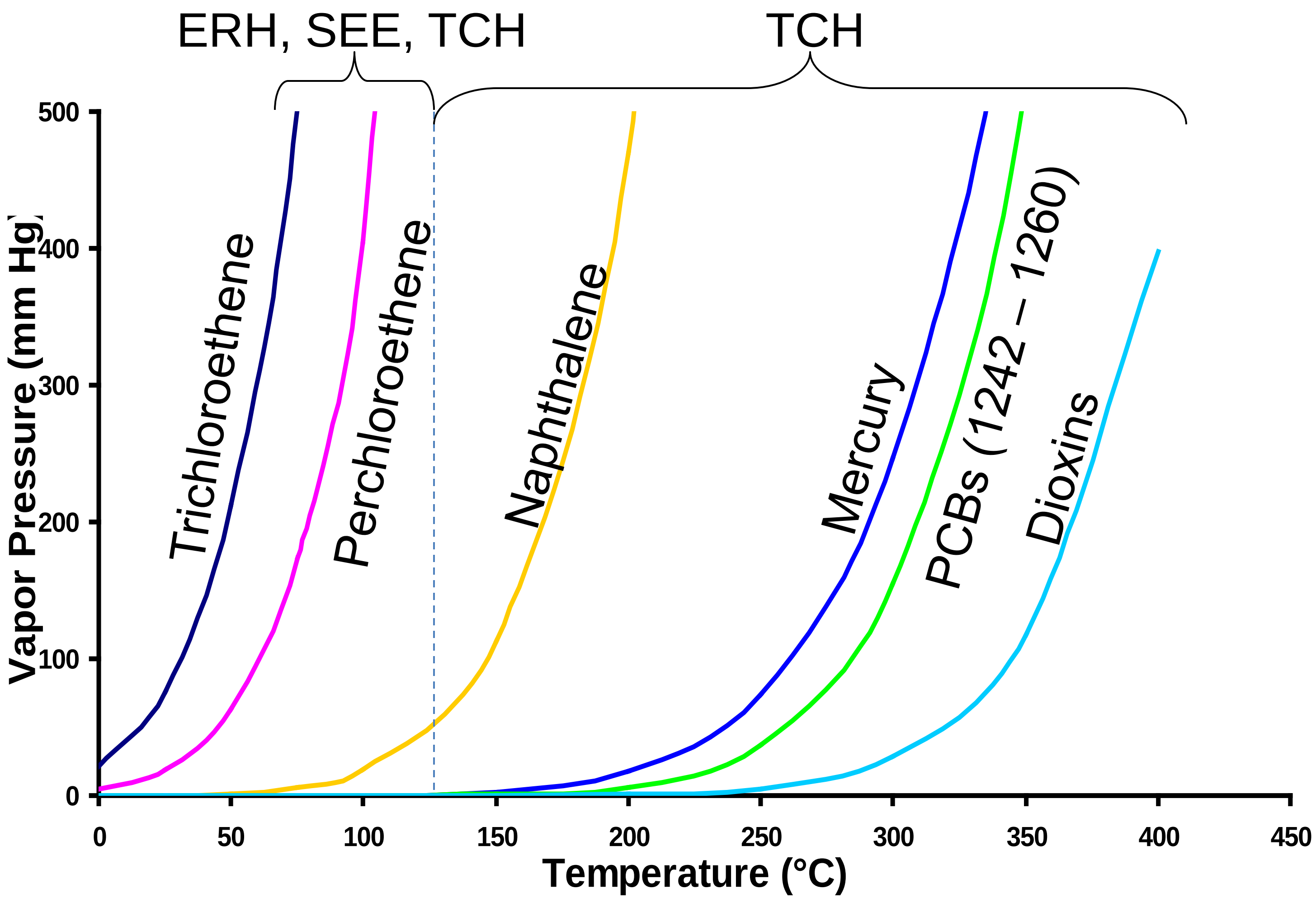


SEE* - Heating governed by **hydraulic conductivity** ($f\sim10^6$); ≤ B.P. of water; High permeability settings



*Offered by TerraTherm, Inc.

Vapor Pressure vs. Temperature



Vapor pressures increase exponentially during heating

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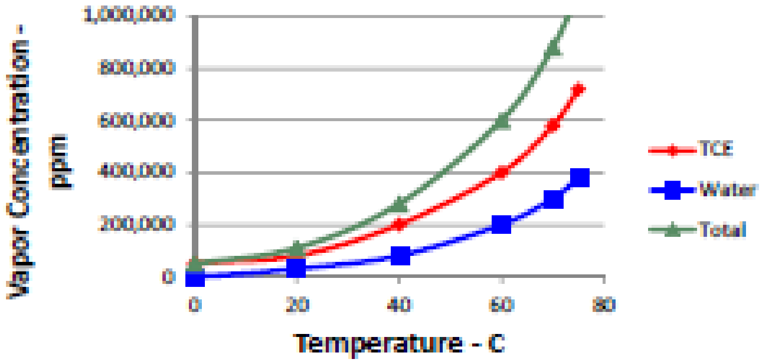
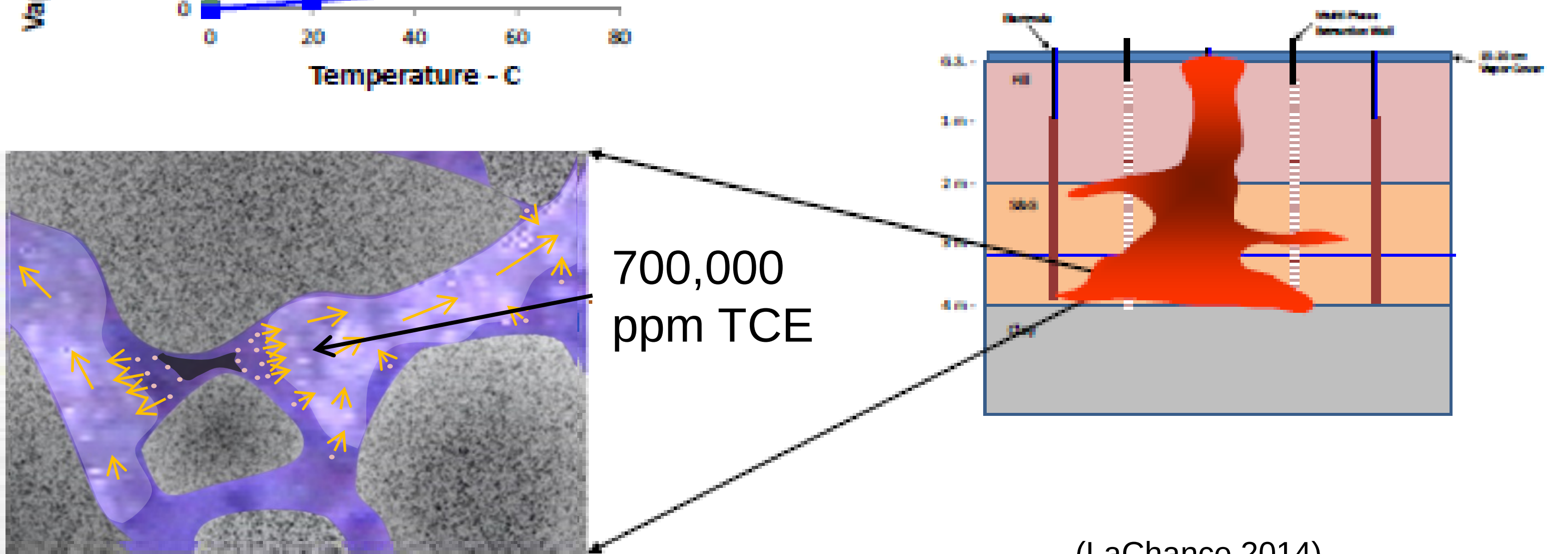
TCE Volatilization, Pore Scale

700,000 ppm TCE possible in vapor phase in pore spaces near NAPL at >80°C





(LaChance 2014)

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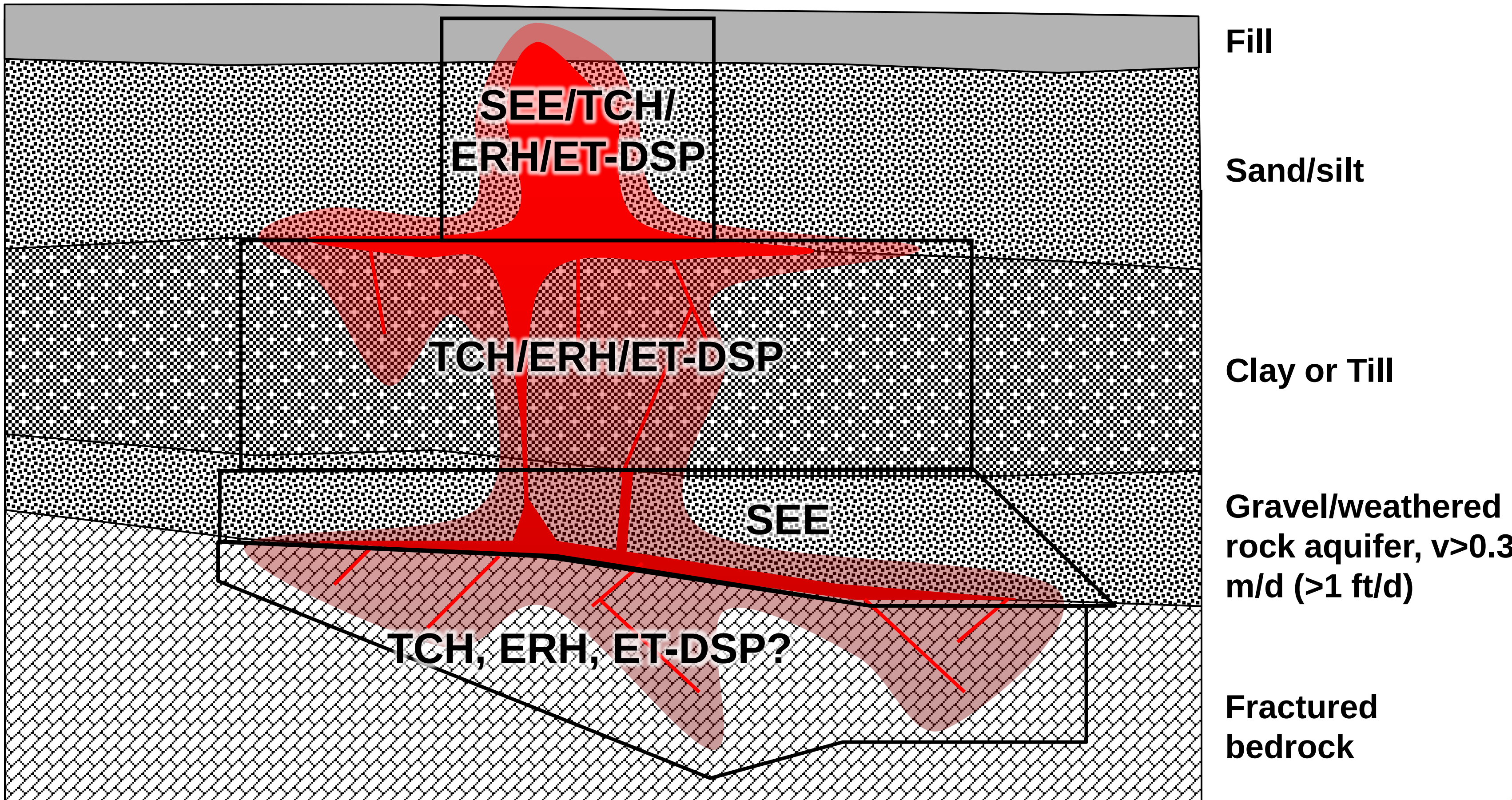
Applicable Technologies in Each Zone



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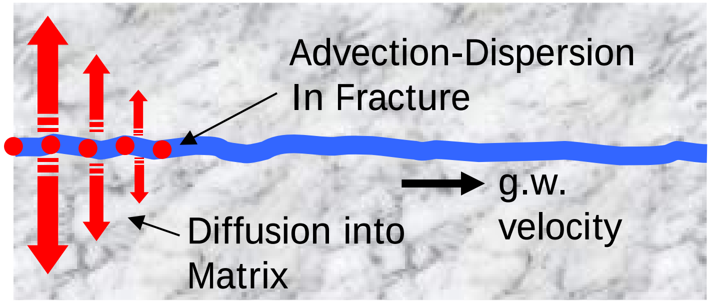
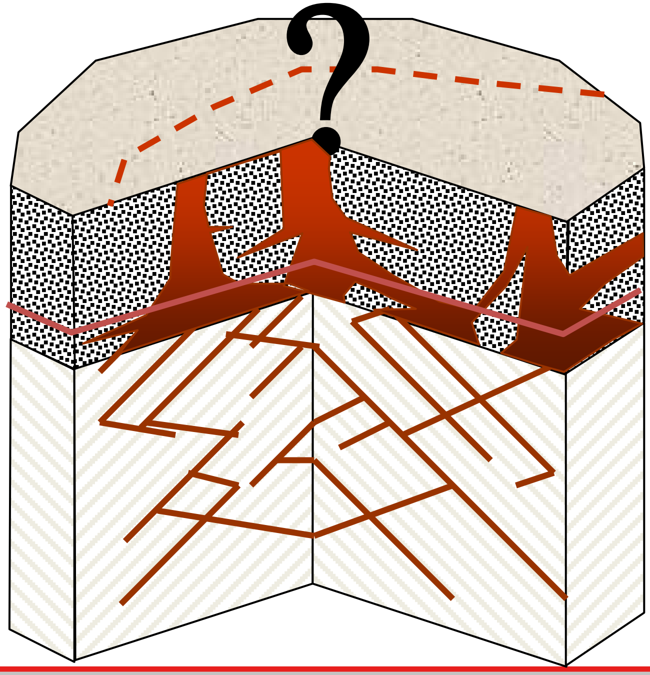
Challenge of Removing CVOCs from Fractured Rock

COCs present in matrix



Fracture-dominated flow



Unknown maximum depth

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Thermal in Rock

- Heat matrix and fractures to boiling temperatures
- Ensure steam capture and extraction – co-located heating and extraction wells
- Match heating technology for matrix with rock properties
  - Porosity, permeability
  - Resistivity
- Ensure heating of fracture zones

SEE at Edwards AFB Site 61, CA

Fractured granite

(quartz monzonite)

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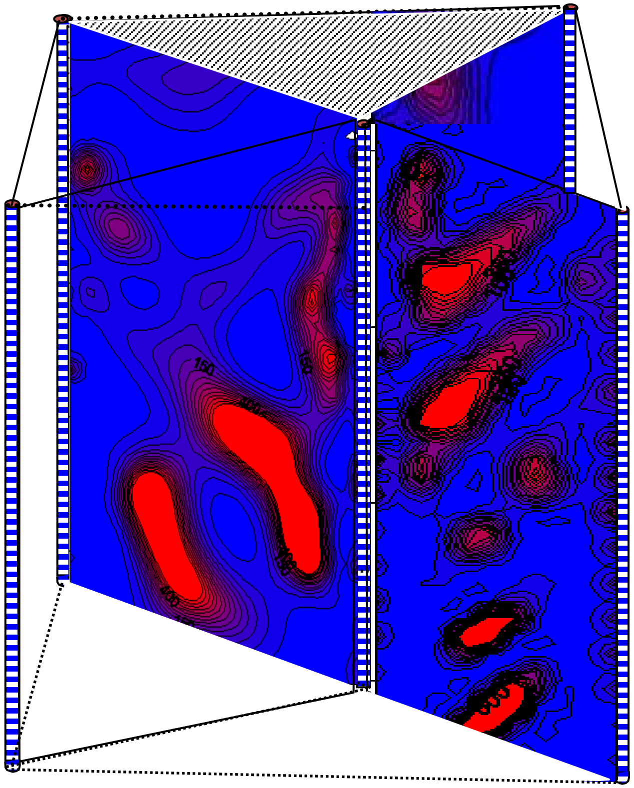
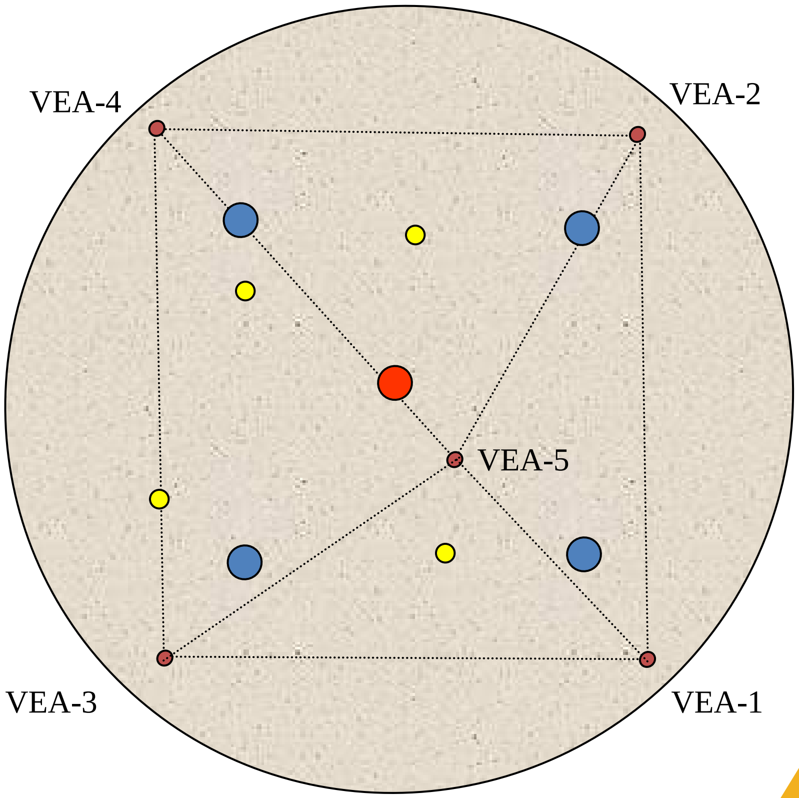
SEE at Edwards AFB Site 61, CA

Edwards AFB Electrical Resistance Tomography (ERT) Data Planes during SEE





⇒ **It is difficult to heat fractured rock with steam alone**

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Is Resistivity Low Enough for ERH/ ET-DSP™ to be Applicable in Rock?

- 600 Volt limit for "low voltage" permits
- Typical applied voltages 100-200 V
- Near surface step potential limitations (Health & Safety)
  - For deep sites, can apply higher voltages
- Each site has a maximum voltage which can be safely used and permitted
  - Most sites: 600 V
  - Required soil resistivity: < 500 &·m

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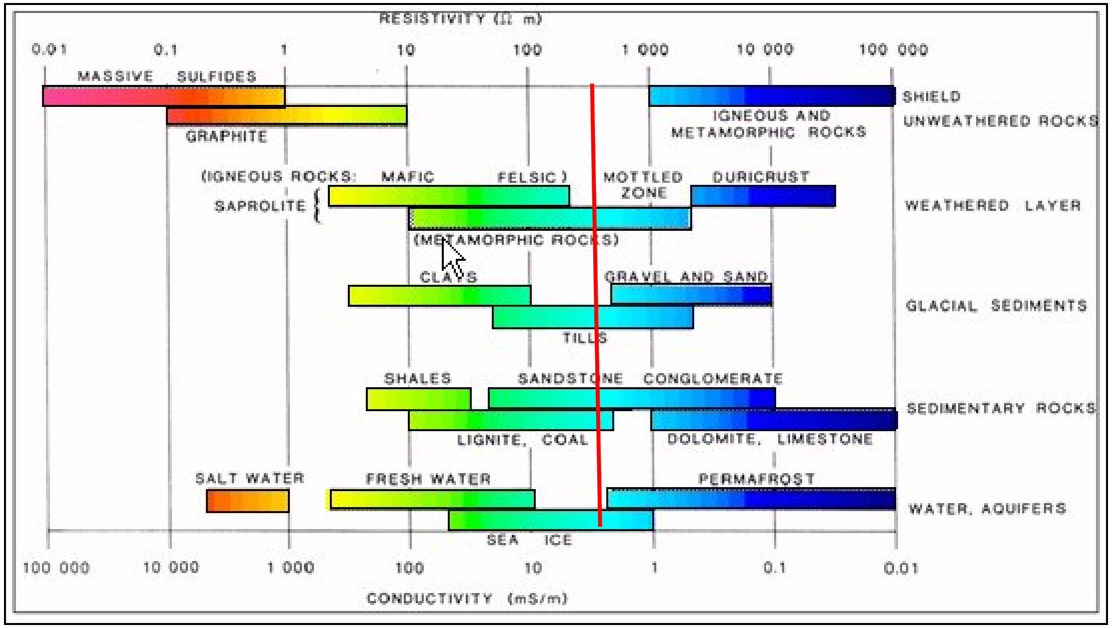
Electrical Resistivity



Palacky (1987)

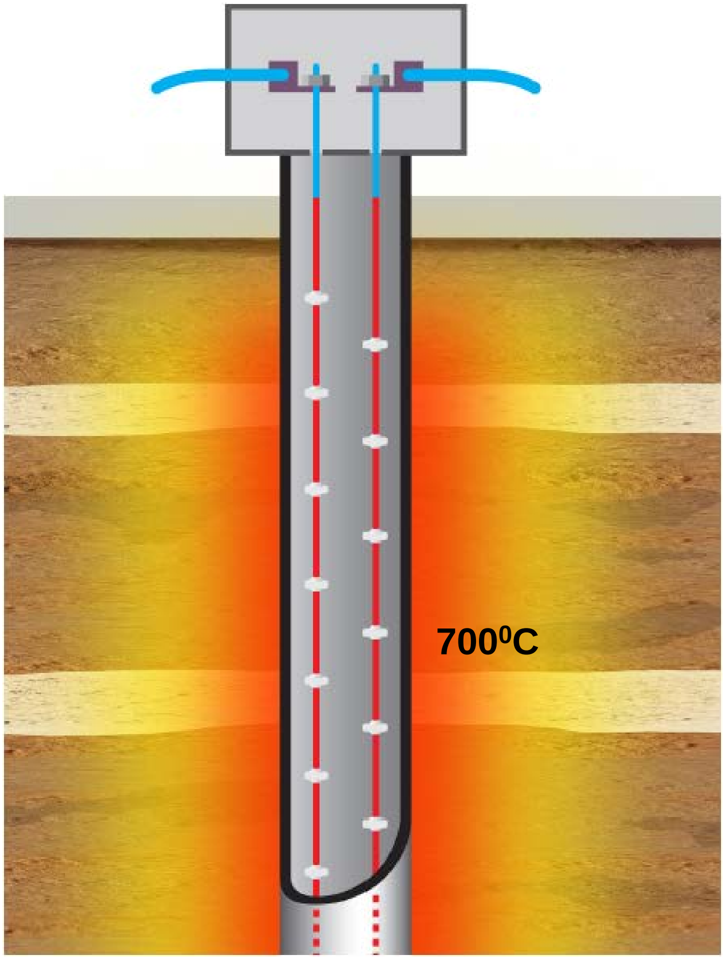
Palacky, G.V. (1987), **Resistivity characteristics of geologic targets**, in Electromagnetic Methods in Applied Geophysics, Vol 1, Theory, 1351

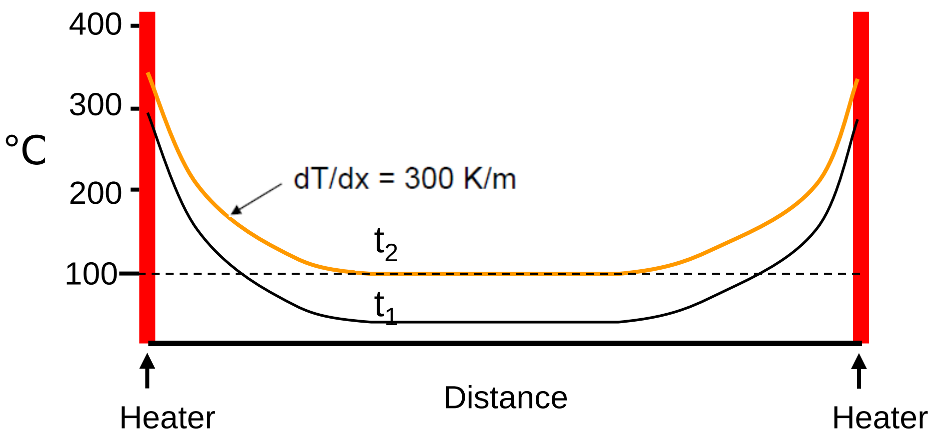
Implications:

- Solid bedrock in itself cannot be heated using ERH – it is too resistive
- More porous rock need to be wet

TCH: Thermal Conduction Heating

Applicable to Virtually All Rock Types





$t_{1,2}$ = temperature progression over time

$$Q = K \times dT/dx$$

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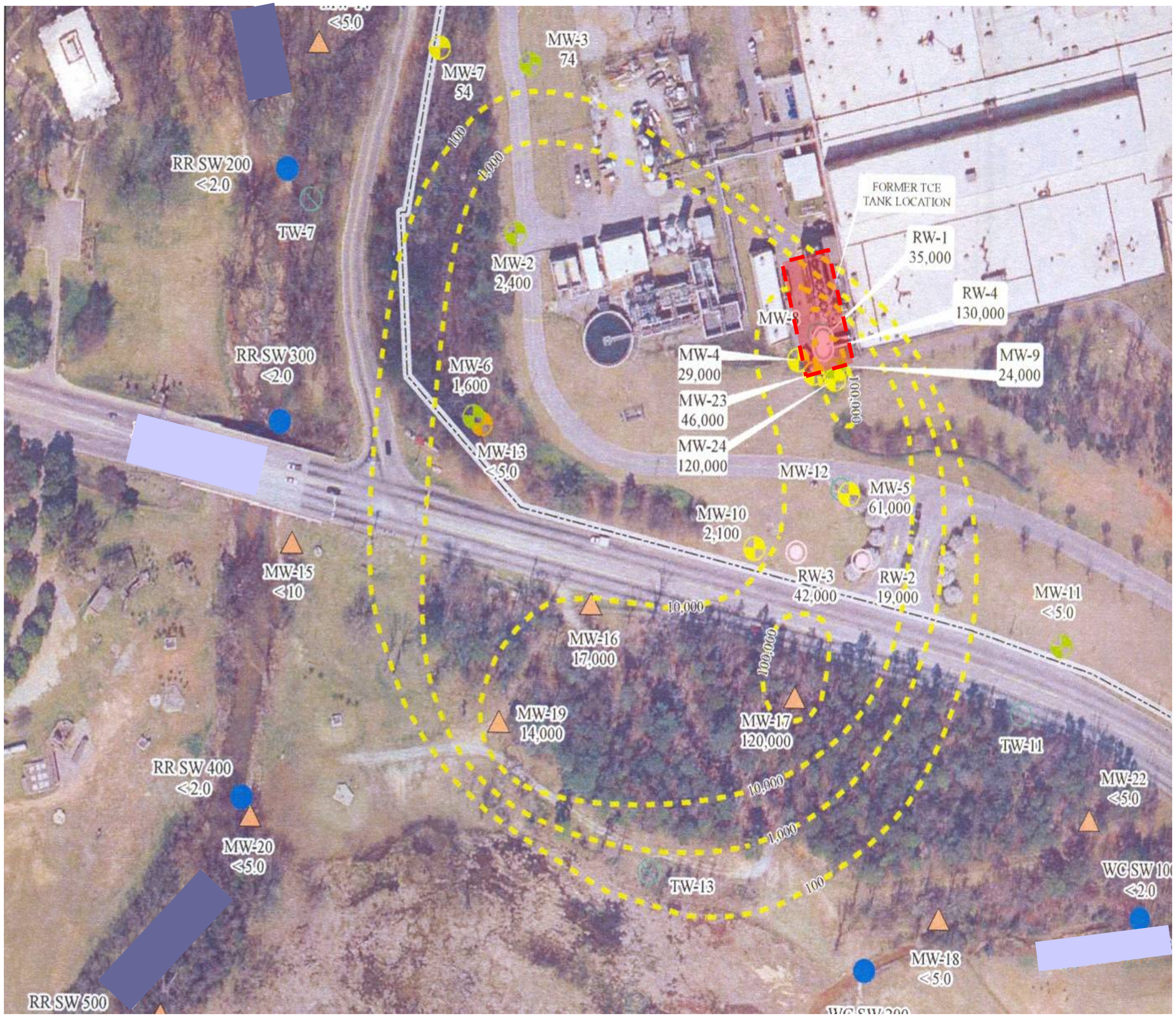
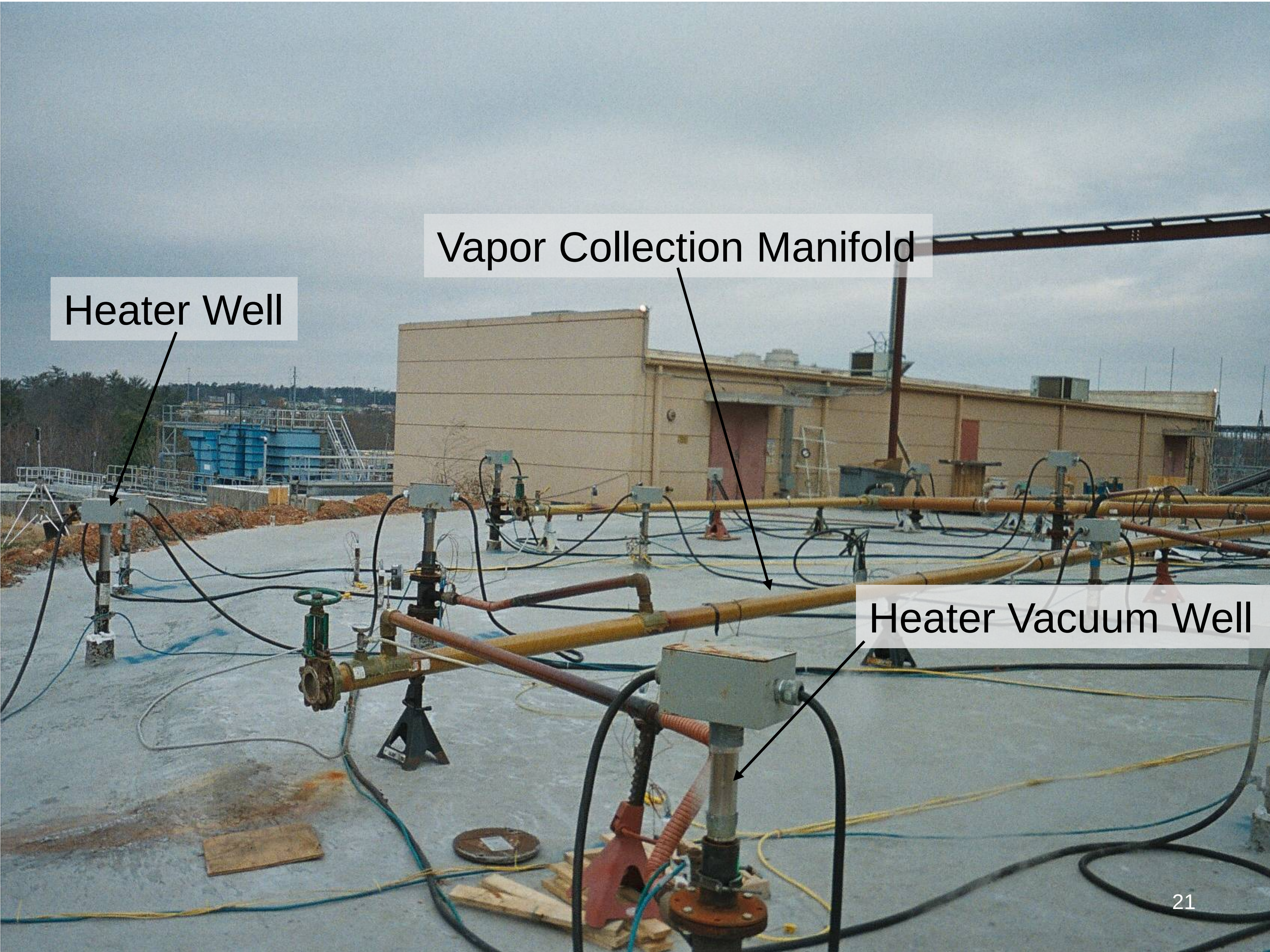
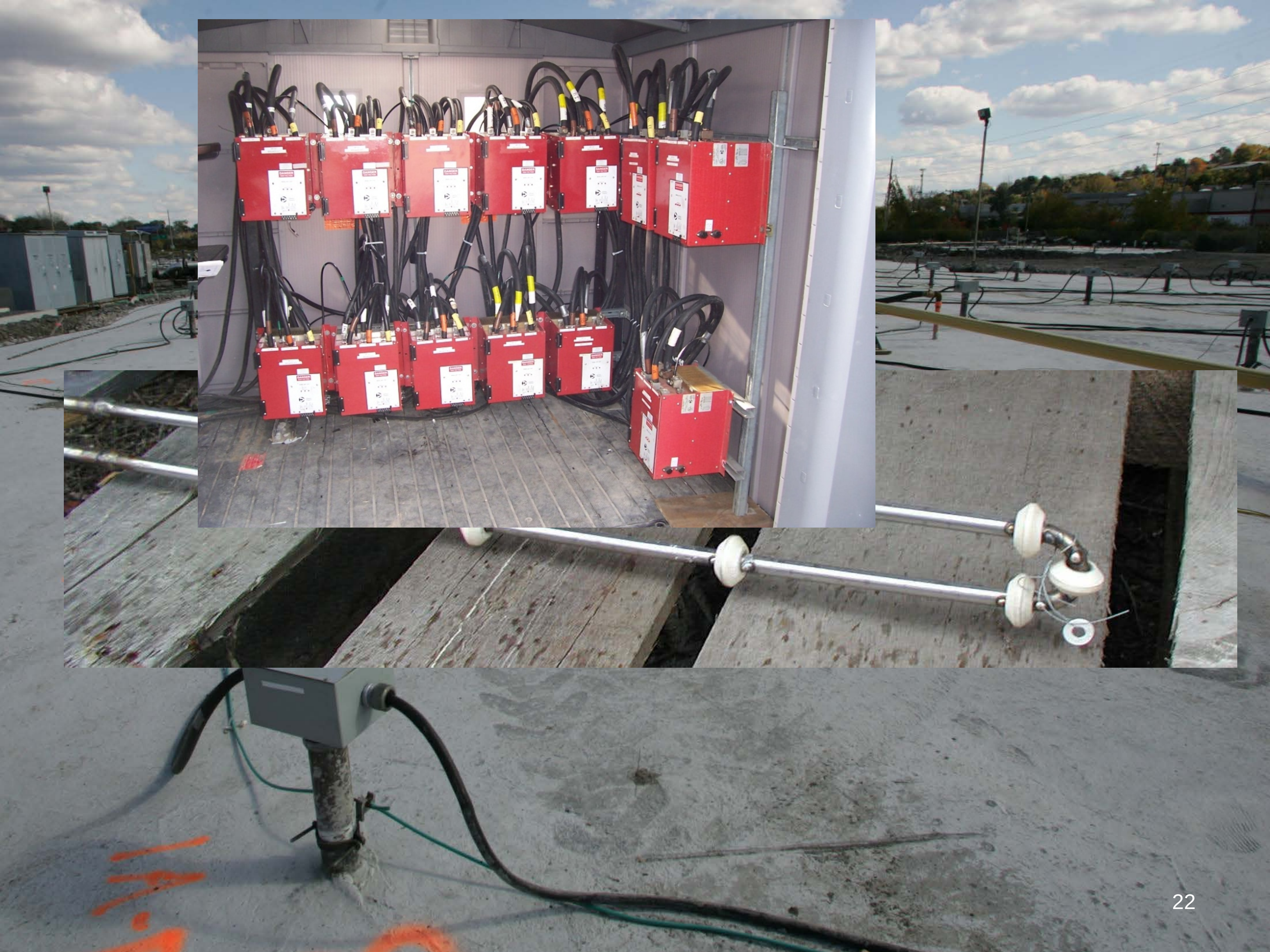
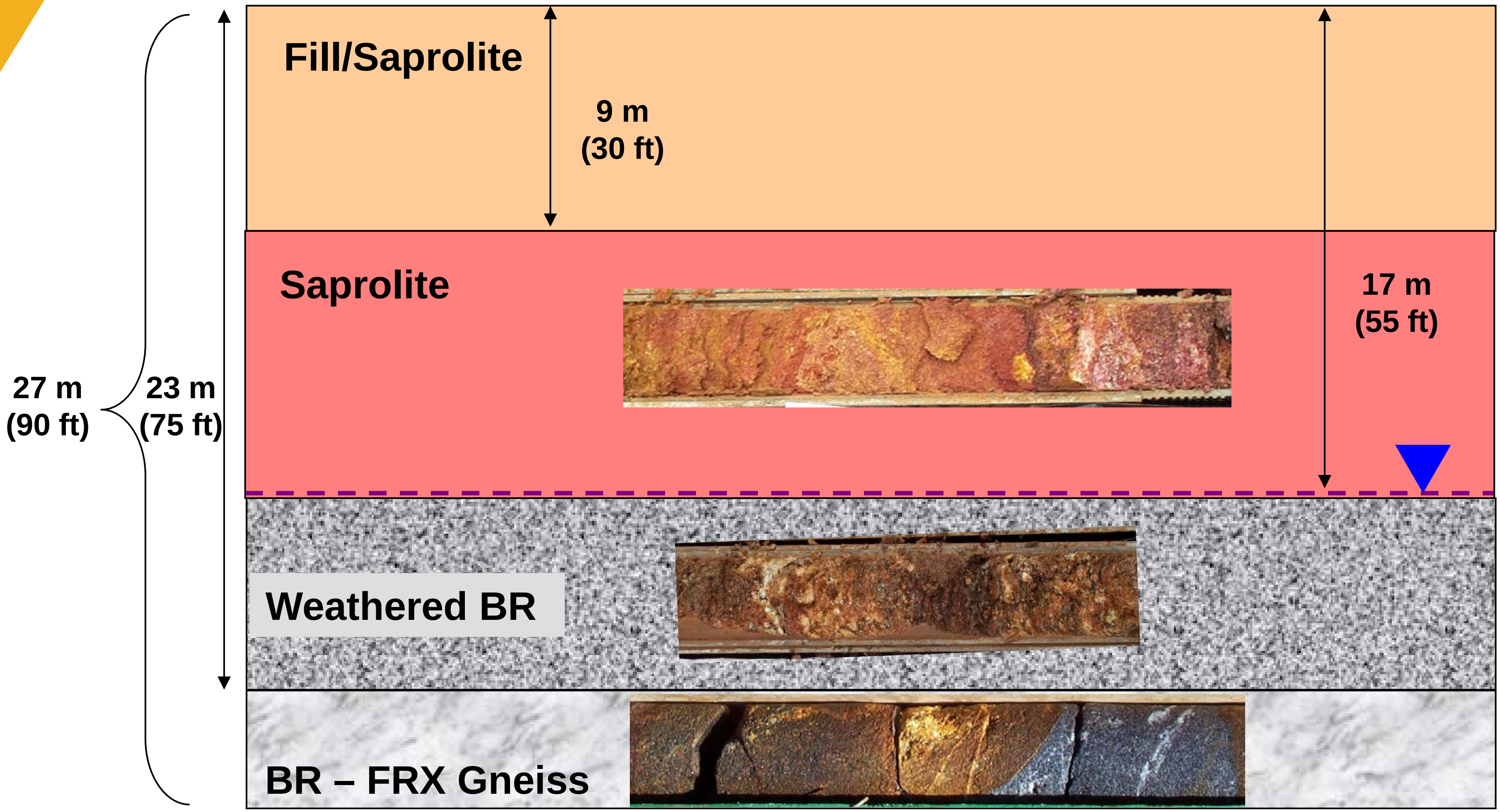
TCH in Fractured Rock Site, SC




Vapor Collection Manifold
Heater Well
Heater Vacuum Well



Conceptual Cross-Section Through Treatment Zone



Treatment zone = 6,650 m^3 (8,700 cy)

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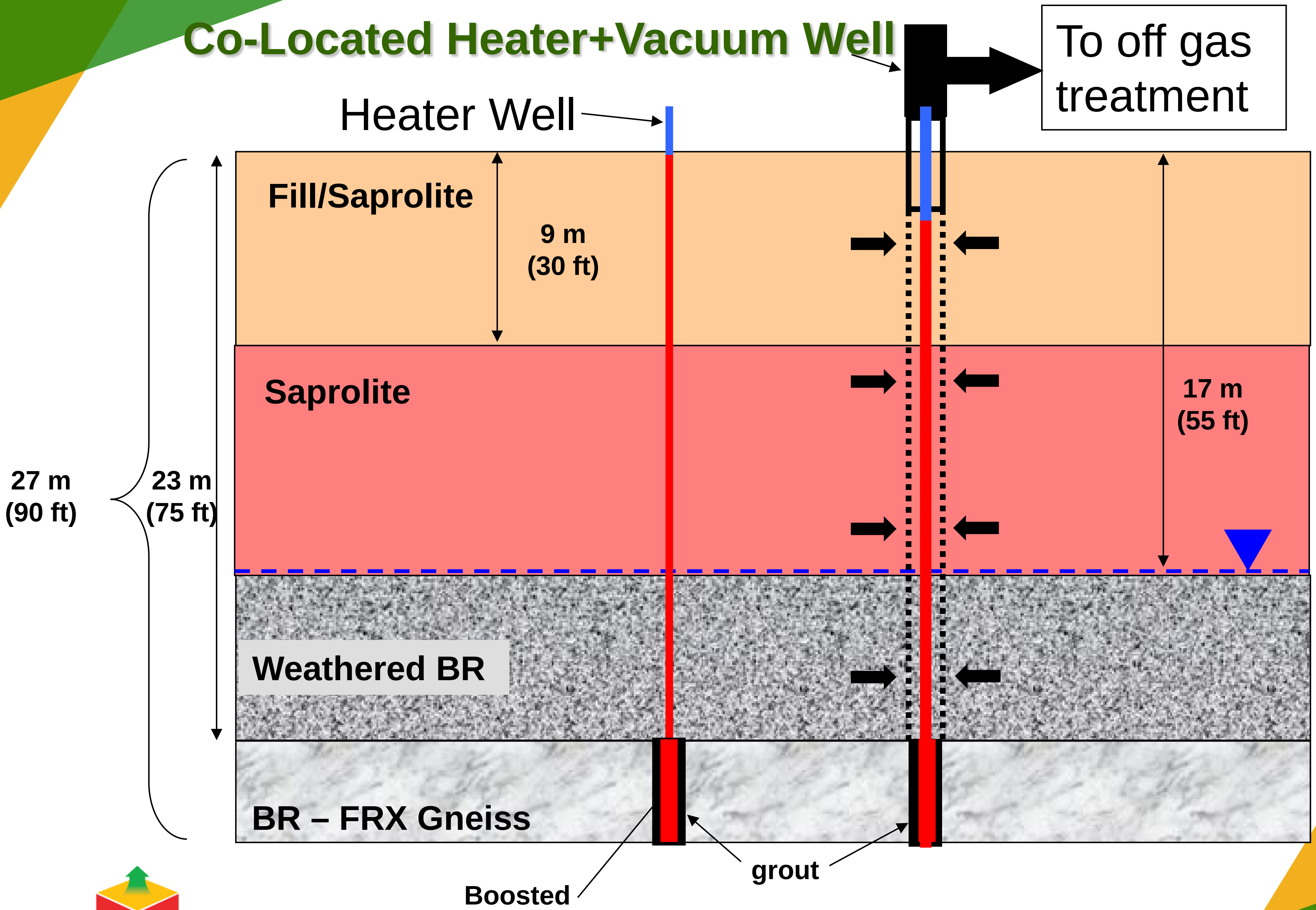
Co-Located Heater+Vacuum Well



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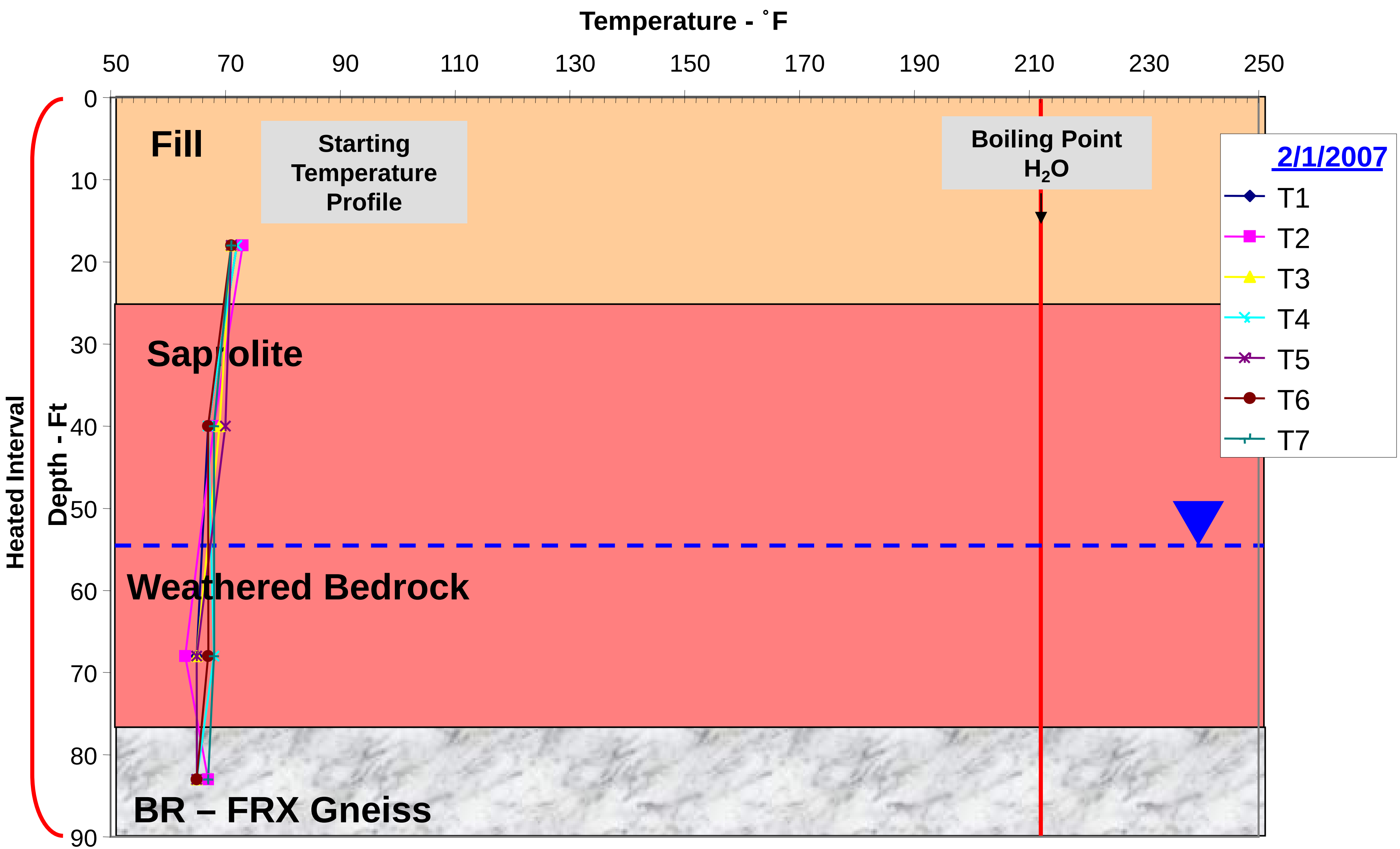
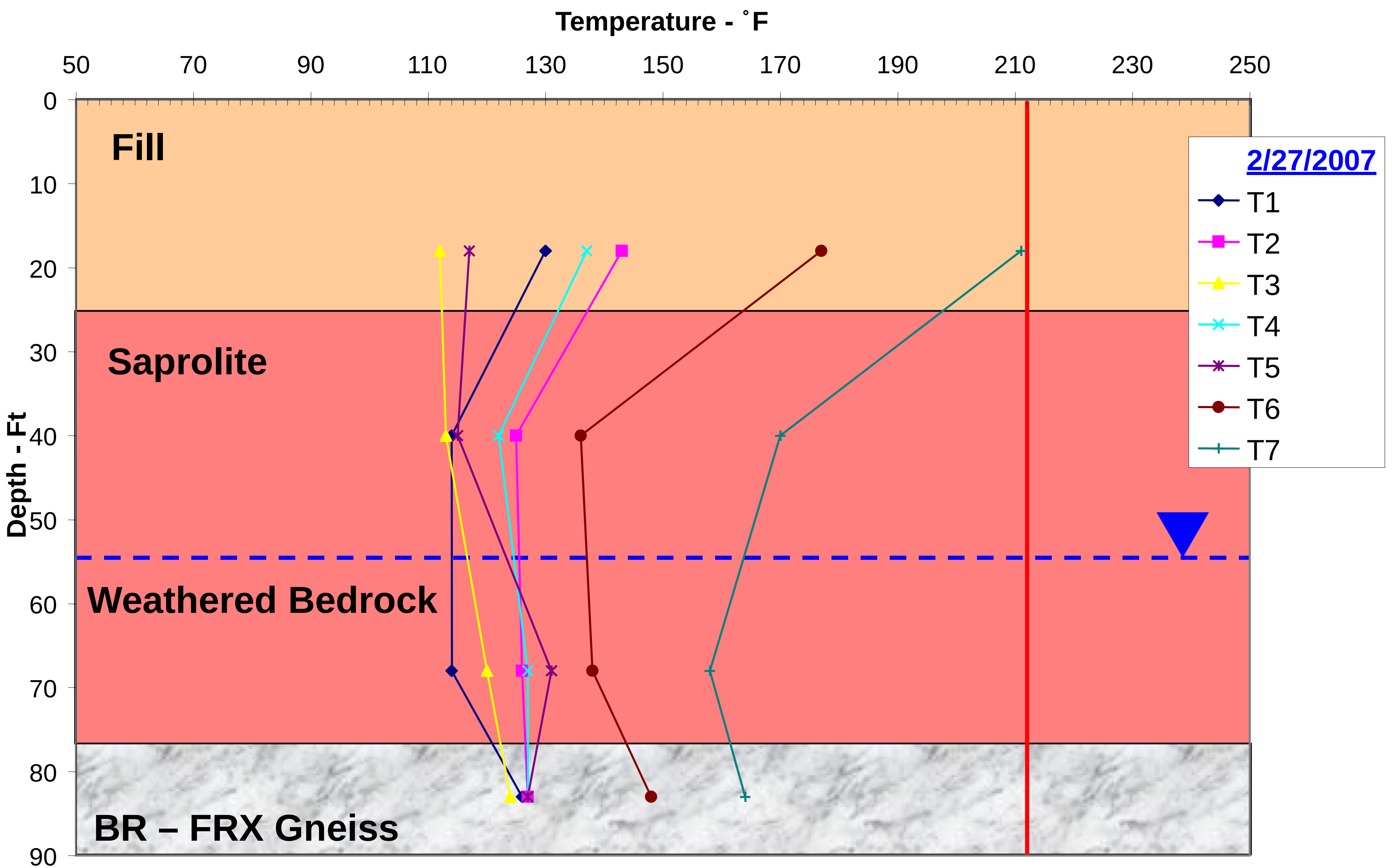
Temperature Profiles at Thermocouples T1 - T7



Temperature Profiles at Thermocouples T1 - T7



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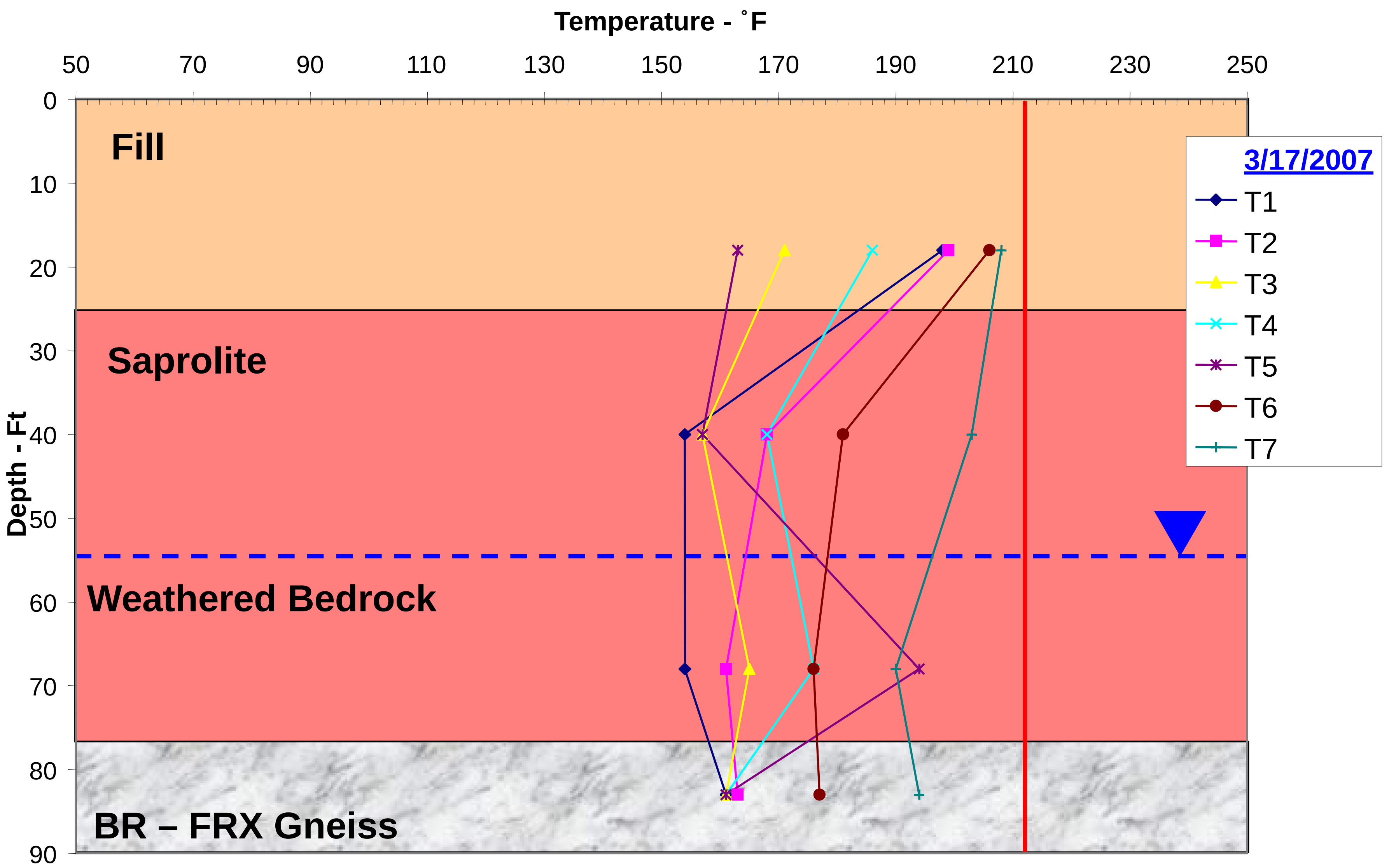

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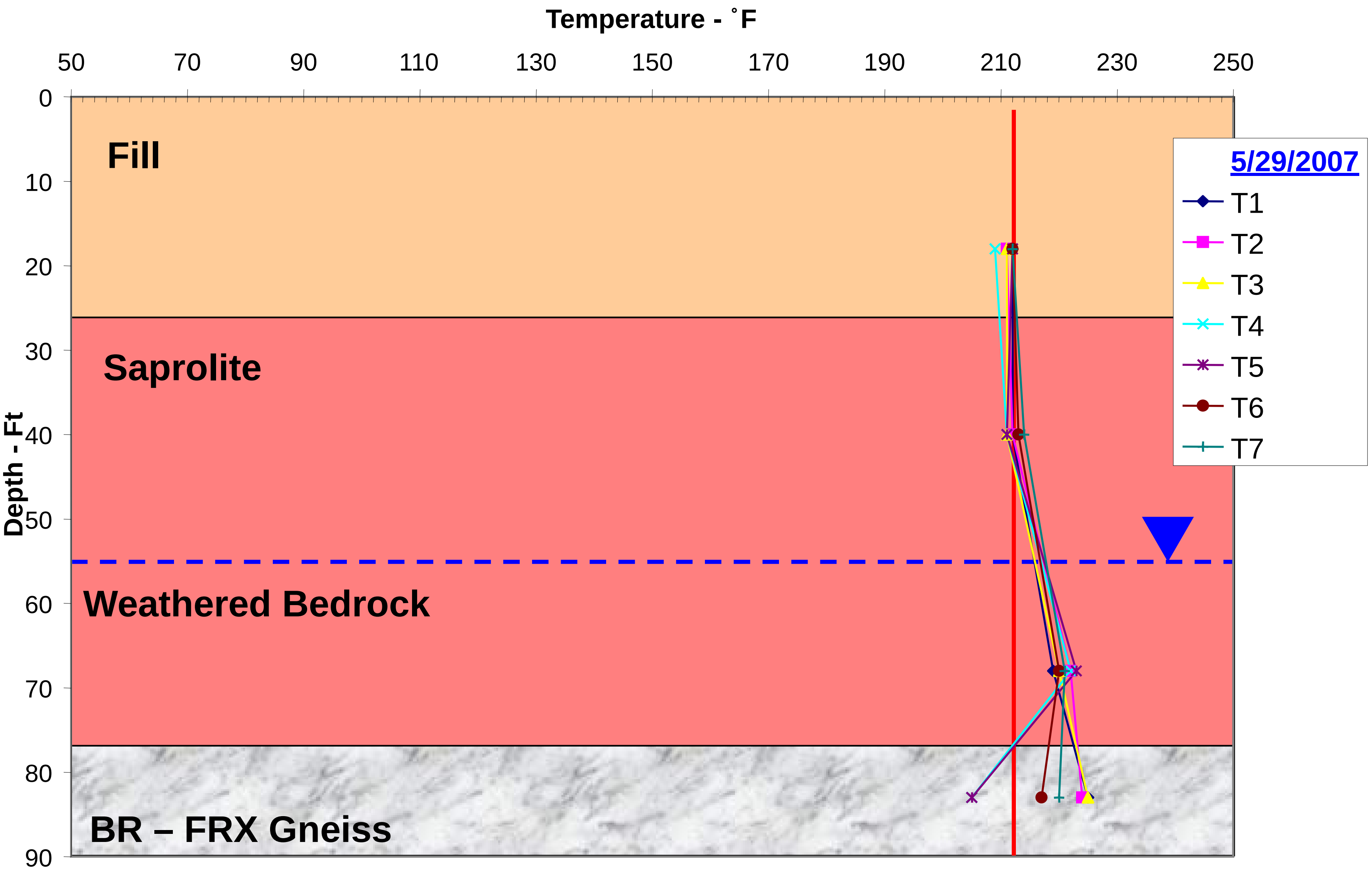
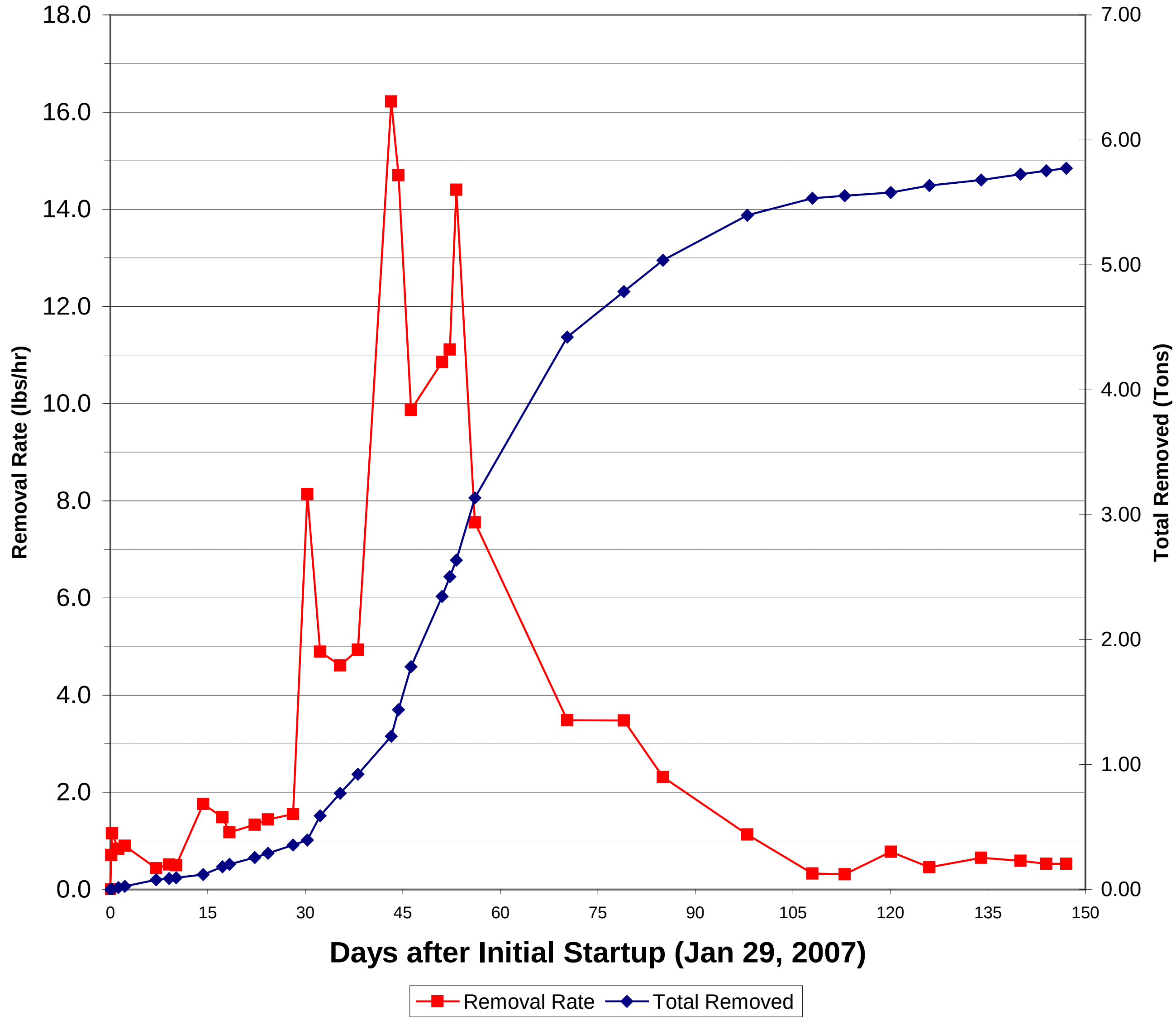


Mass Removal During TCH Treatment



~5,500 kg (~12,000 lbs) of TCE

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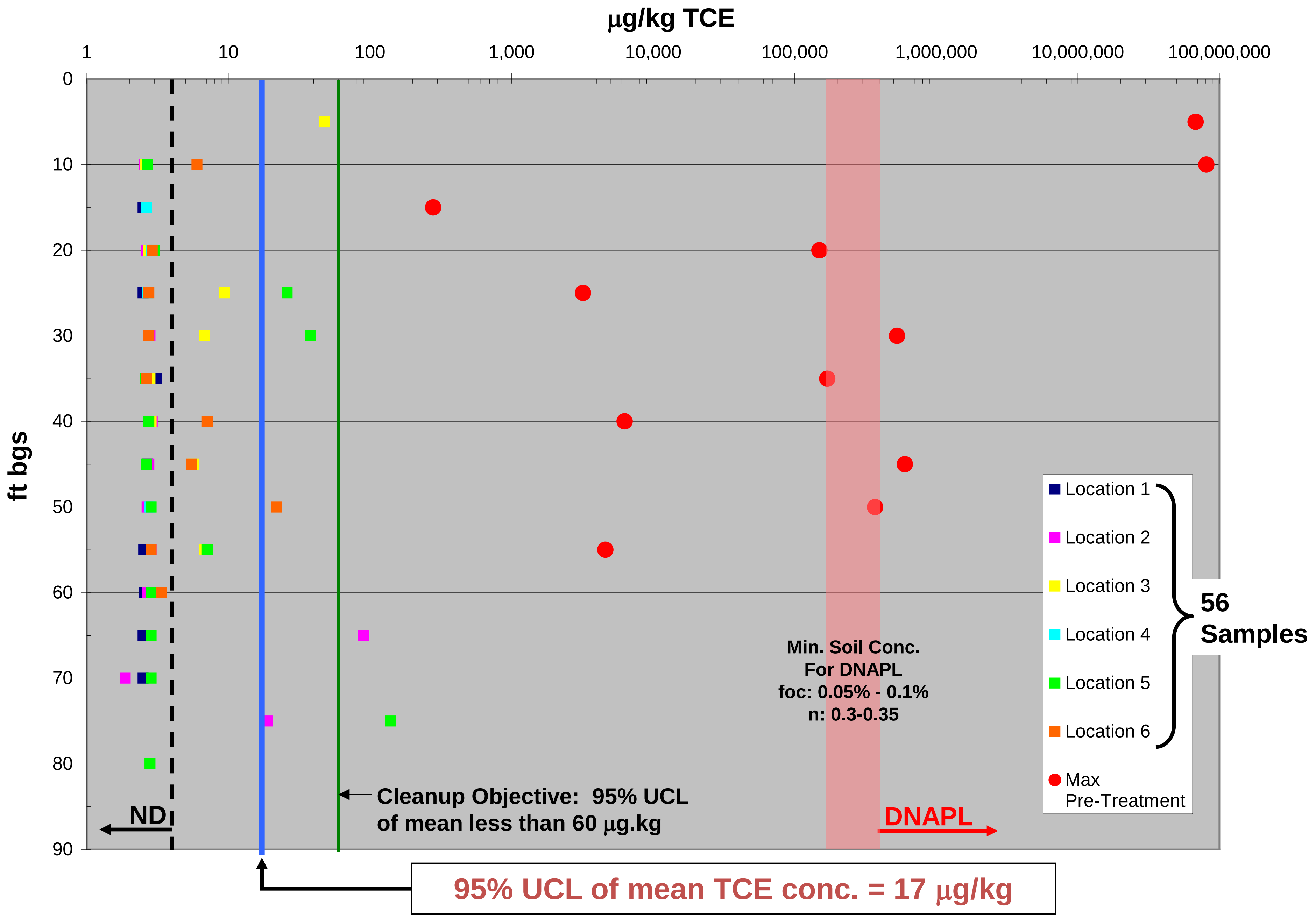
Confirmation Soil Data From TCH Project in SC



Summary, SC Case Study

- Rock heats even easier than overburden (less water and porosity)
- Extremely low post-TCH concentrations
- TCH effective in heating and treating DNAPL in crystalline rock

Data Needs:
Collection and Analysis of Rock Samples

Ascertain pre- vs. post-thermal COCs in rock matrix, with distance from fractures

ESTCP Project ER200715, NAWC, E. Trenton, NJ

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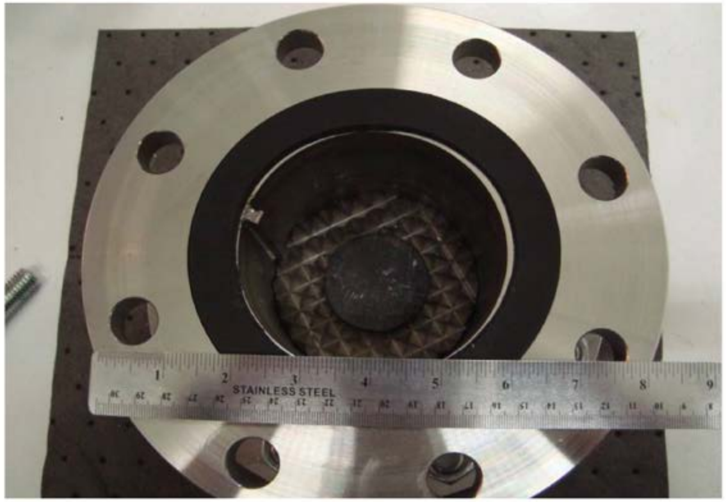



Queens Univ. Rock Crusher (Kueper et al.)

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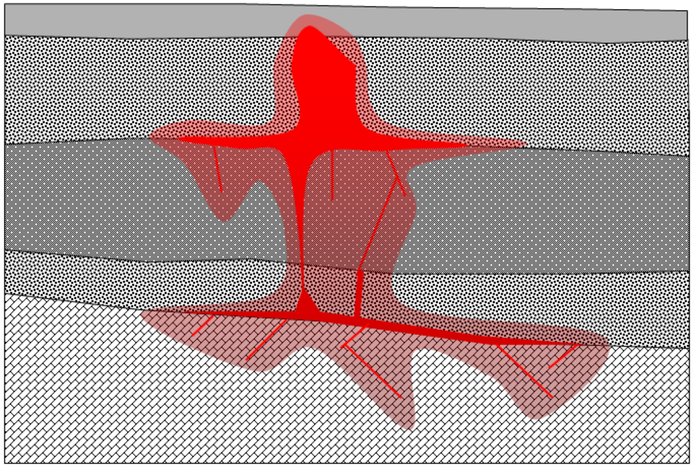
TCH at SRSNE Superfund Site, Southington, CT

0.7 ha (1.7 acres)
36,000 m³ (47,000 cy)
Overburden and upper 1.5 m (5 ft) of fractured rock, in operation
Co-Located heater and vacuum extraction borings

Conclusions

- Fractured rock sites are very different
- Select thermal technology based on site conditions
- TCH is the most reliable technology for heating fractured rock
- Use TCH in combination with SEE when necessary (high groundwater flux)
- ERH may also work in wet porous rock
- Ensure that vapors are captured



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References

- Heron, G., R.S. Baker, J.M. Bierschenk and J. LaChance. 2008. Use of Thermal Conduction Heating for the Remediation of DNAPL in Fractured Bedrock. Paper P-003, in: Bruce M. Sass (Conference Chair), *Remediation of Chlorinated and Recalcitrant Compounds—2008.* Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2008). Battelle Press, Columbus, OH.
- Lebrón, C. 2010. U.S. Navy Demonstrates Thermal Conductive heating for DNAPL Removal in Fractured Rock. *USEPA Technology News & Trends* (December, 2010).
- NAVFAC. 2012. ESTCP Final Report: *Dense Non Aqueous Phase Liquid (DNAPL) Removal from Fractured Rock Using Thermal Conductive Heating (TCH)*. Prepared by C. Lebrón, D. Phelan, G. Heron, J. LaChance, S.G. Nielsen, B. Kueper, D. Rodreguez, A. Wemp, D. Baston, P. LaCombe and F.H. Chapelle. Contract Report CR-NAVFAC ESC-EV-1202, Port Hueneme, CA.

Questions?

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