Science Supporting Clean-up at INL: Bioremediation of the Test Area North Trichloroethylene Plume

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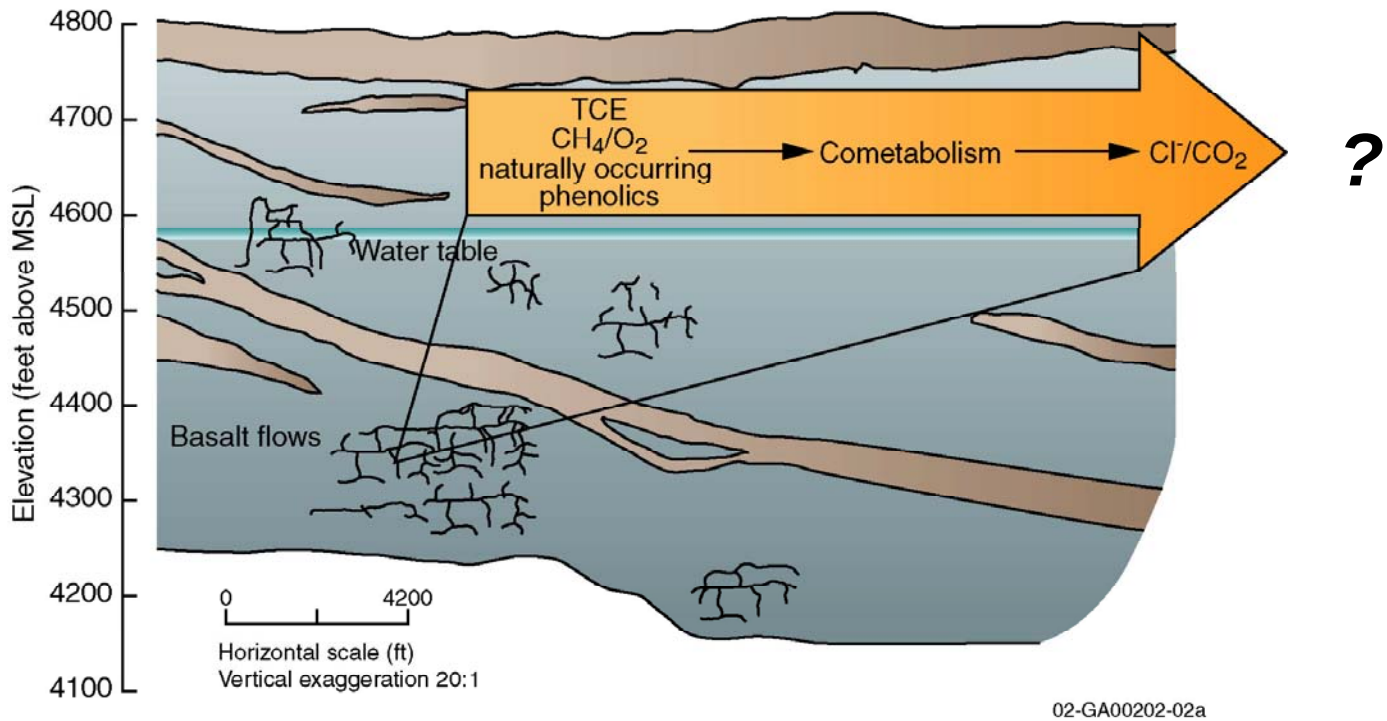


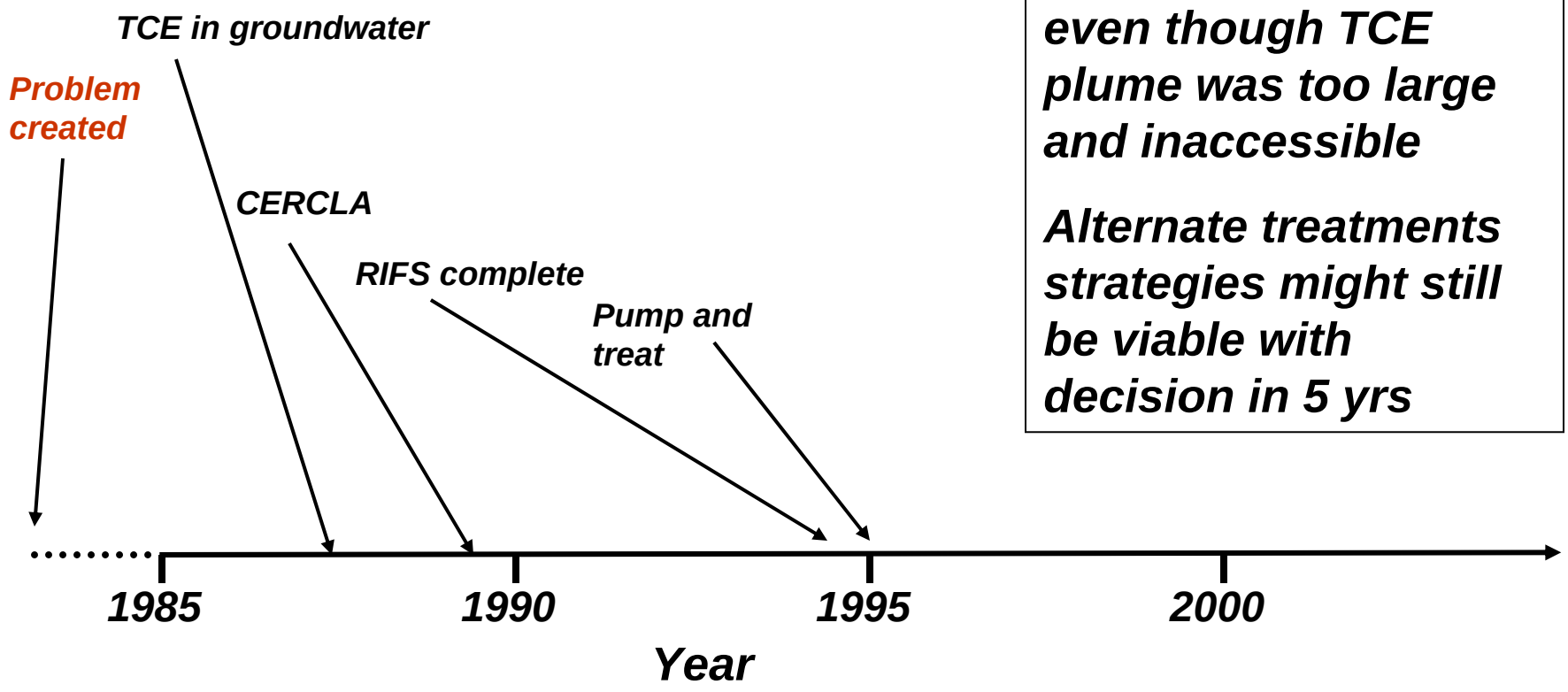
TCE contamination plume at TAN

- ***Injection well disposal of liquid wastes to the Snake River Plain Aquifer (1953 to 1972)***
- ***Aquifer (ca. 65 m below land surface) in a thick sequence of fractured basalts and thinner interbedded sediments***
- ***TCE plume extends 3,100 m in aquifer, 25,000 m^2 (concentrations from 5 to 32,000 ug/L)***

Early clean-up related activities at TAN

DOE SC-sponsored Subsurface Science Program: use-inspired basic research (1985 to ~1996)

TAN problem identified, solution initiated



Pump-and-treat technology chosen even though TCE plume was too large and inaccessible

Alternate treatments strategies might still be viable with decision in 5 yrs

Technical challenges

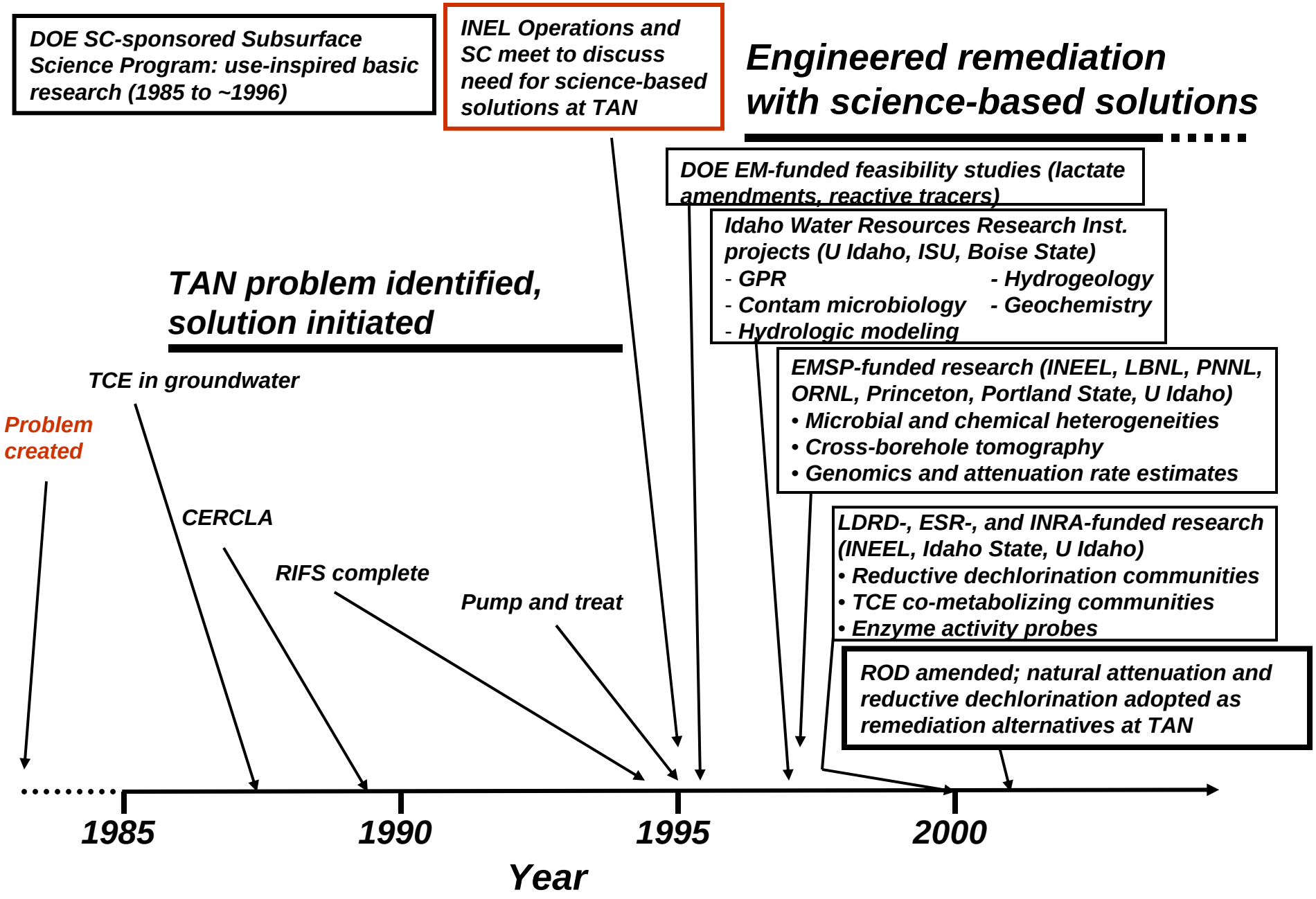
- ***Vertical distribution and primary flowpaths of TCE was unknown; fractured rock geology was responsible***
- ***Locations and components of biologically active zones, if any, were not apparent***
- ***Biological and geochemical heterogeneity was inferred but not understood***
- ***Residual TCE in basalt matrix?***

Non-technical challenges

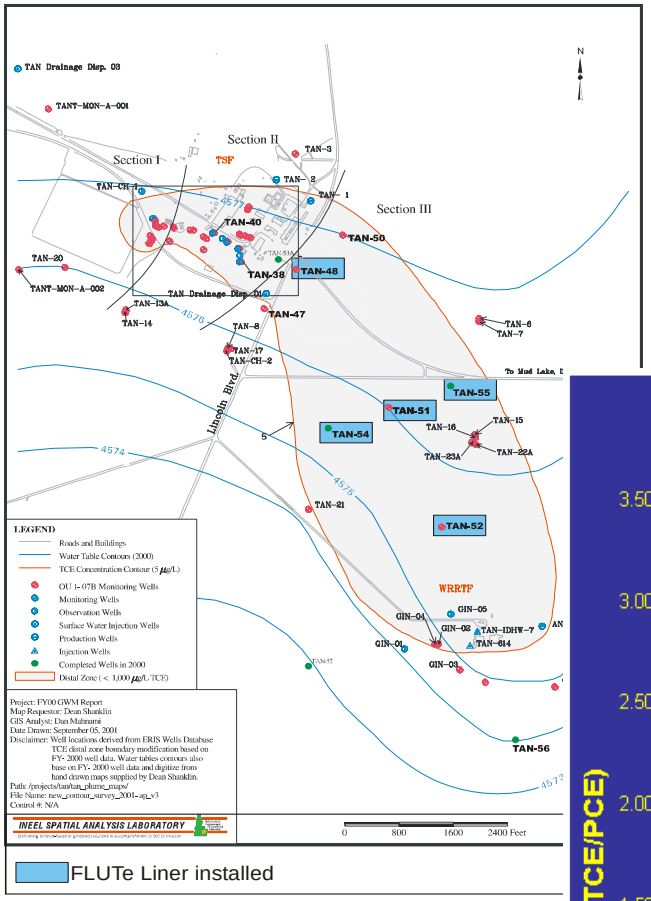
- *Regulatory hurdles (legal); sample collection is expensive,*
- *Coordination problems associated with conflicting goals (balance between cleanup and research)*
- *National lab procedural barriers (legal, administrative)*
- *Stakeholder concerns (real vs. perceived)*
- *Absence of authoritative planning*
- *Inexperience with cross-disciplinary science*
- *Knowledge of subsurface science not fully integrated in decision-making*

Coalescence of opportunities in 1996

- *Science in hand:*
  - *Characterization of subsurface microbes, geochemistry, geophysics*
  - *High integrity sampling techniques*
- *Team:*
  - *Interdisciplinary, multi-institutional (labs, universities, industry)*
  - *Interested, motivated operations scientists*
- *Timing*
  - *End of DOE's Subsurface Science Program*
  - *TAN managers in need of and able to accept assistance*

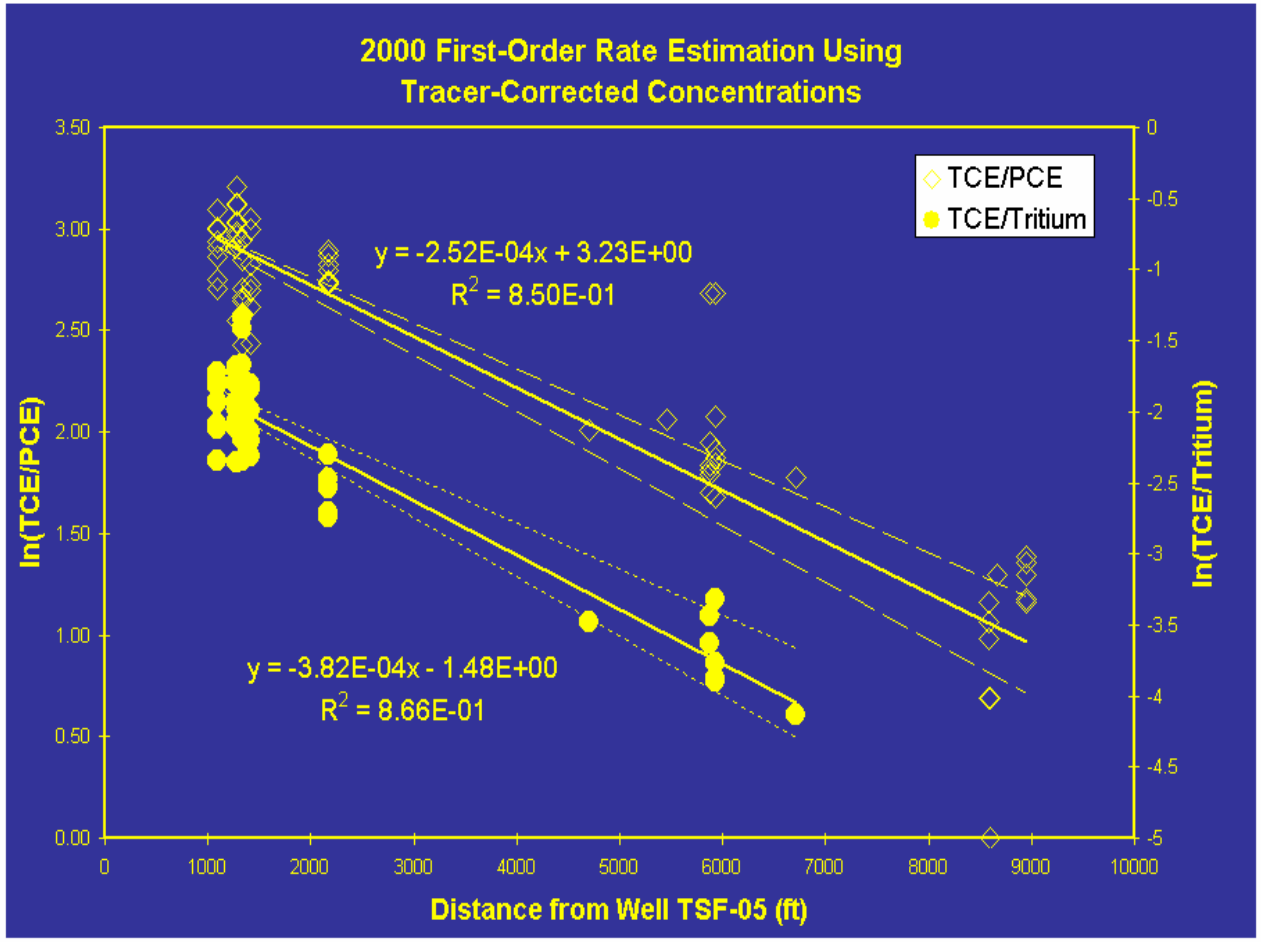

DOE SC-sponsored Subsurface Science Program: use-inspired basic research (1985 to ~1996)
INEL Operations and SC meet to discuss need for science-based solutions at TAN
Engineered remediation with science-based solutions
DOE EM-funded feasibility studies (lactate amendments, reactive tracers)
Idaho Water Resources Research Inst. projects (U Idaho, ISU, Boise State)
- GPR
- Hydrogeology
- Contam microbiology
- Geochemistry
- Hydrologic modeling
TAN problem identified, solution initiated
EMSP-funded research (INEEL, LBNL, PNNL, ORNL, Princeton, Portland State, U Idaho)
• Microbial and chemical heterogeneities
• Cross-borehole tomography
• Genomics and attenuation rate estimates
TCE in groundwater
Problem created
CERCLA
RIFS complete
Pump and treat
LDRD-, ESR-, and INRA-funded research (INEEL, Idaho State, U Idaho)
• Reductive dechlorination communities
• TCE co-metabolizing communities
• Enzyme activity probes
ROD amended; natural attenuation and reductive dechlorination adopted as remediation alternatives at TAN
1985
1990
1995
2000
Year

TAN TCE Plume Map



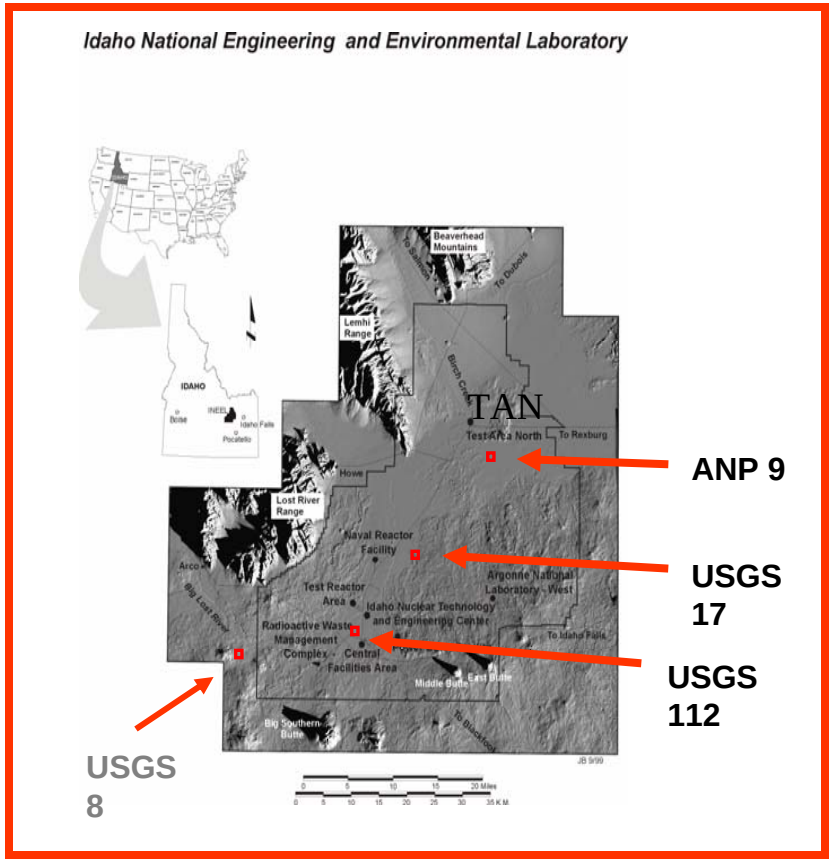
2-mi long TCE plume at TAN is stable by natural attenuation

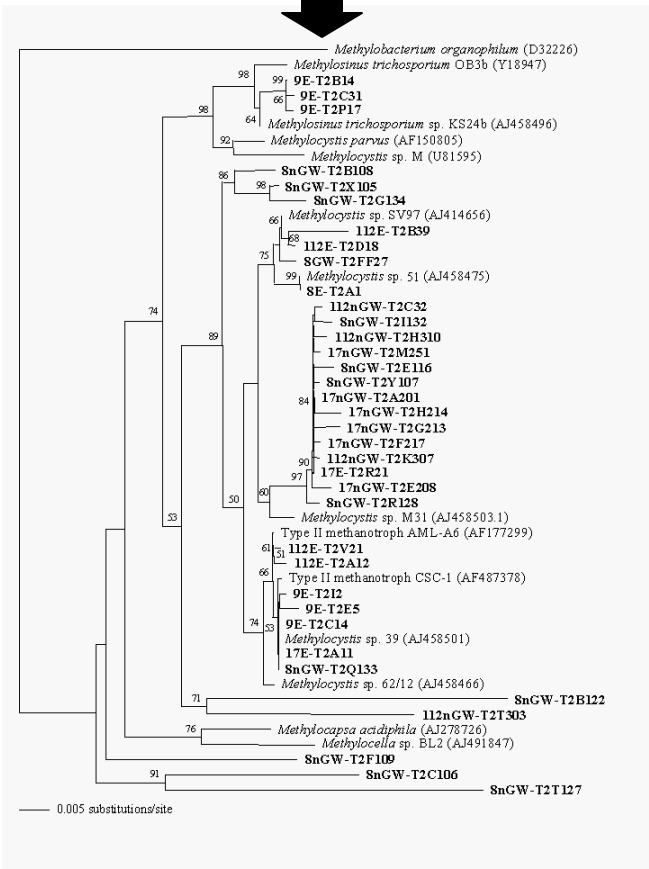
Natural attenuation verified by TCE/PCE and TCE/tritium ratios; first-order degradation rate apparent for TCE

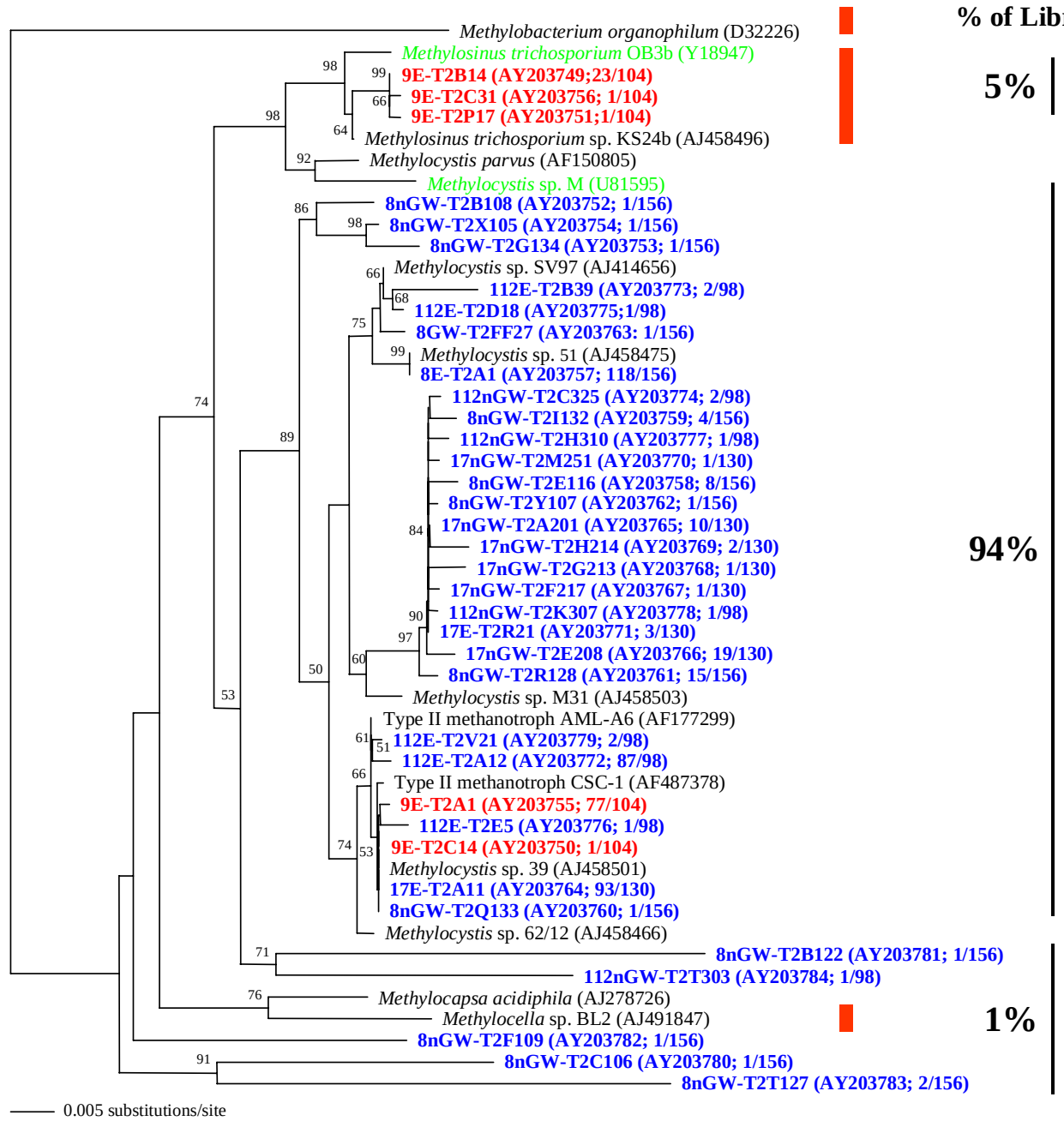


But what is responsible for the natural attenuation? Need cause-and-effect relationship between contaminant loss and mechanism (NRC, 2000)

- *Amplify methanotroph DNA from groundwater, enrichments, isolates (16S rDNA, mmoX, pmoA)*
- *Clone products, screen clones, sequence unique products*
- *Compare to RDP/GenBank*
- *Phylogenetic analysis*







% of Library

5%

94%

1%

Type II methanotroph tree

- **5% of clones related to *Methylosinus trichosporium.* All from ANP 9 (near TAN)**
- **94% of clones related to *Methylocystis* spp. TCE co-metabolism not evident in this clade**
- **1% of clones are unique, undescribed methanotrophs**

Clones from ANP 9; clones from other SRPA wells; TCE co-metabolizing methanotrophs

Recently detected in TAN plume

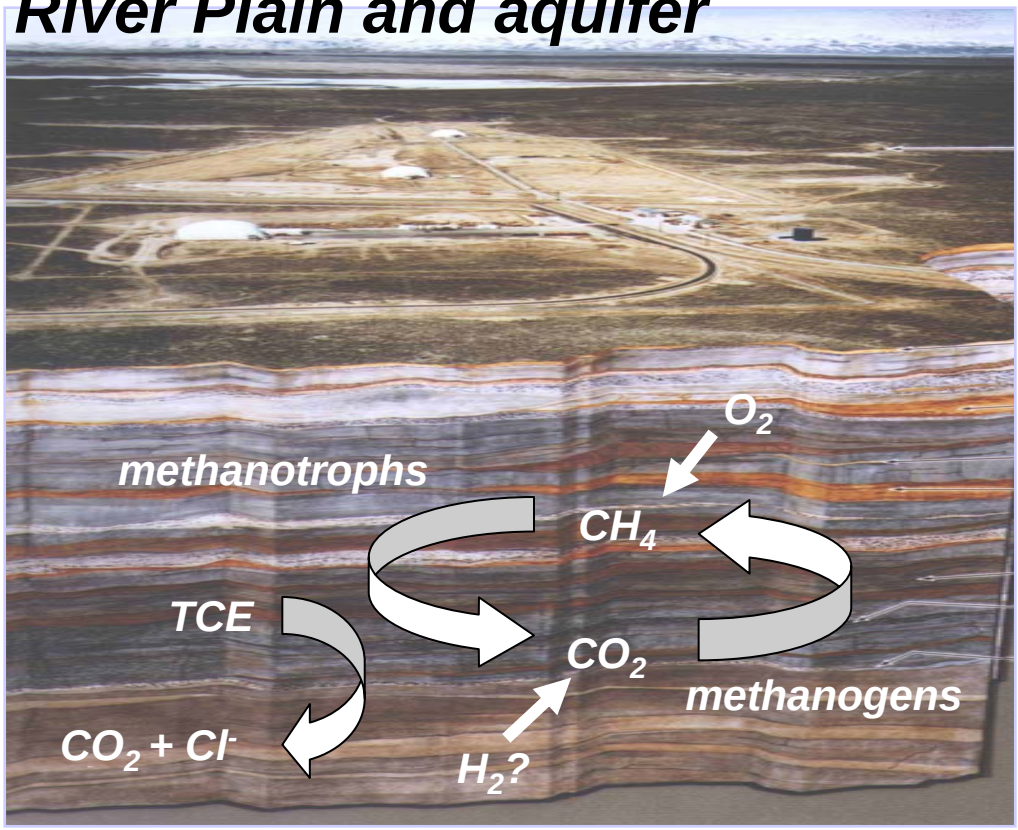
Biogeochemistry of Snake River Plain and aquifer

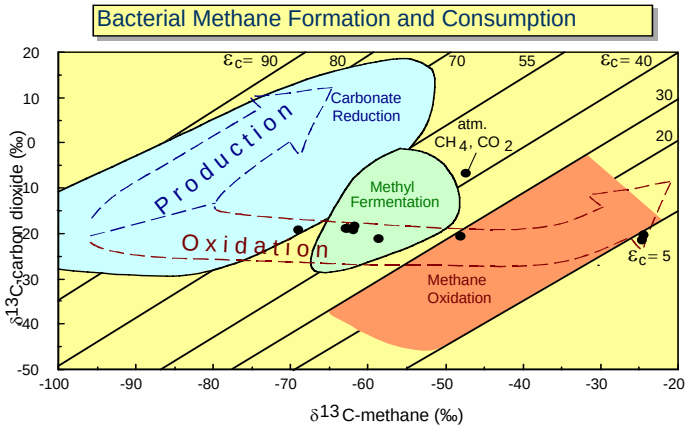
Large, freshwater, semi-confined aquifer; water temp: 12-13 C

Low numbers of cells in this low carbon system

Vadose zone appears to be one of the most austere subsurface microbial habitats

Archaea *and* Bacteria *present*





after Whiticar, M.J., 1999. Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. *Chemical Geology* , Vol. 161, No. 1-3, p. 291-314.

$$\varepsilon C \;-\; 10^{3} \ln \alpha_C \;-\; 10^{3}(\alpha_C - 1) \;-\; \delta^{13}C_{CO2} - \delta^{13}C_{CH4}$$

C-1 cycling in the Snake River Plain aquifer:

Dissolved methane is biogenic (by CO_2 reduction); appears to be used by methanotrophs

Aquifer contains both methanogens and methanotrophs

Coupled Biogeochemical Process Evaluation for Conceptualizing TCE Co-Metabolism

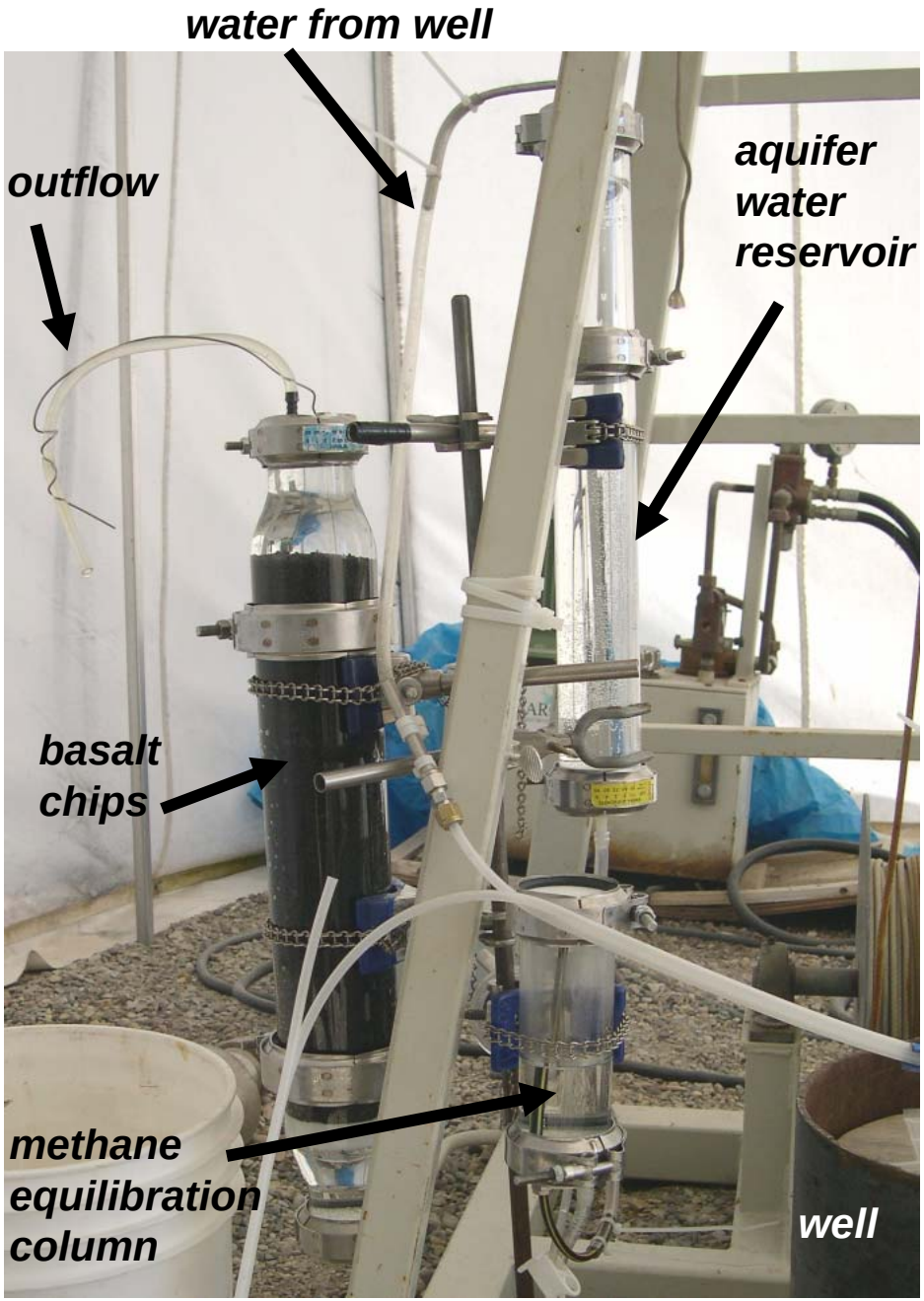
Objectives:

Determine TCE co-metabolism rates coupled to methane levels and fluid movement rates in primary flow paths

Derive the enzyme activities of TCE co-metabolizing cells

Determine the relationship between the expression levels of key genes related to TCE co-metabolism and the presence of a broader array of proteins to TCE transformation rates

Obtain an improved conceptual model of natural attenuation at DOE sites and refine computational models of natural attenuation



flow-through in situ reactor (FTISR)

Costs

- ***Prior to science-based solutions (i.e., using pump-and-treat): $43 M for 30 yrs***
- ***Costs realized due to science-based solutions (i.e., with reductive dechlorination and monitored natural attenuation): $35.4 M for 15 yrs***

  ➔ net estimated savings $7.6 M

Broadly applicable technical advances

- ***Recognition of microbial communities responsible for:***
  - ***reductive dechlorination during lactate amendments to treat "hotspot"***
  - ***natural attenuation mechanisms***
- ***Cross-borehole tomography in fractured media***
- ***Genomic and proteomic diagnostics (in progress)***
- ***Enzyme activity probes (in progress)***
- ***Realistic rate estimates for TCE cometabolism (in progress)***

Improved version….?

DOE Sc-sponsored Subsurface Science Program: use-inspired basic research (1985 to ~1996)

TAN problem identified

INL Operations (CWI) and science teams meet to discuss need for science-based solutions at TAN

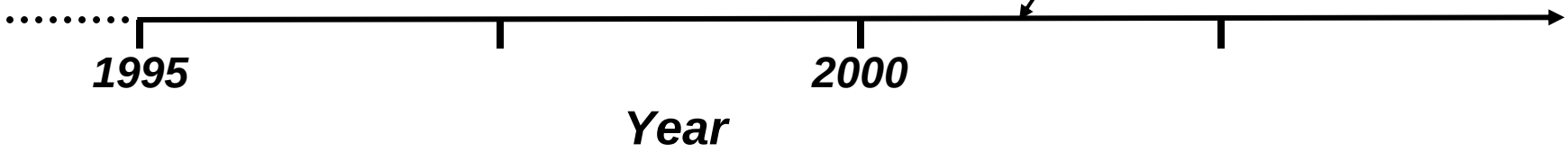
Engineered remediation with science-based solutions ……

Science implemented as overarching campaign

- *Appropriate timing and encouragement*
- *Administrative, regulatory issues handled*
- *Consolidation of existing science, disciplinary integration*
- *Analytical assessment of the problem ➔ gaps identified ➔ recommended solutions*
- *Advisory board (guidelines, tracking progress, infusion of new science, seek parallel problems)*
- *Research coordinated with remediation*
- *Seek other applications of solution-based/use-inspired basic research*
- *Involve universities and students*

DOE EM-funded feasibility studies
Idaho Water Resources Research Inst. projects
EMSP-funded research
LDRD-, ESR-, and INRA-funded research

ROD amended; natural attenuation and reductive dechlorination adopted as remediation alternatives at TAN



Considerations for a Science-Based Approach

- ***Geophysics-geochemistry-hydrology-microbiology linkage***
  - ***Changes to minerals based on biogeochemical processes that change formation, permeability, redox, solubility***
  - ***Increased biomass or gas in target zones***
  - ***Incorporation of detectable labels (e.g., heavy isotopes) based on specific activity***
  - ***Activity-specific reporter mechanisms***
  - ***Better sensors, realistic rate values***
  - ***Non-invasive technologies connecting geophysics, geochemistry, microbiology with data acquired using a real time, continuous, automated platform***
    - ***A center for "embedded networked sensing"?***
    - ***Real-time reporting, prediction, diagnosis, and adaptive manipulation?***
    - ***Intelligent control of cleanup?***
- ***Informing and inspiring public confidence***
- ***Reduced cleanup costs for TAN and other sites? For example, eight DOE sites recently identified with TCE plumes undergoing natural attenuation (127 plumes at 24 DOE sites surveyed)***