SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

Mitigating Acid Rock Drainage with Land-Applied BCR Effluent

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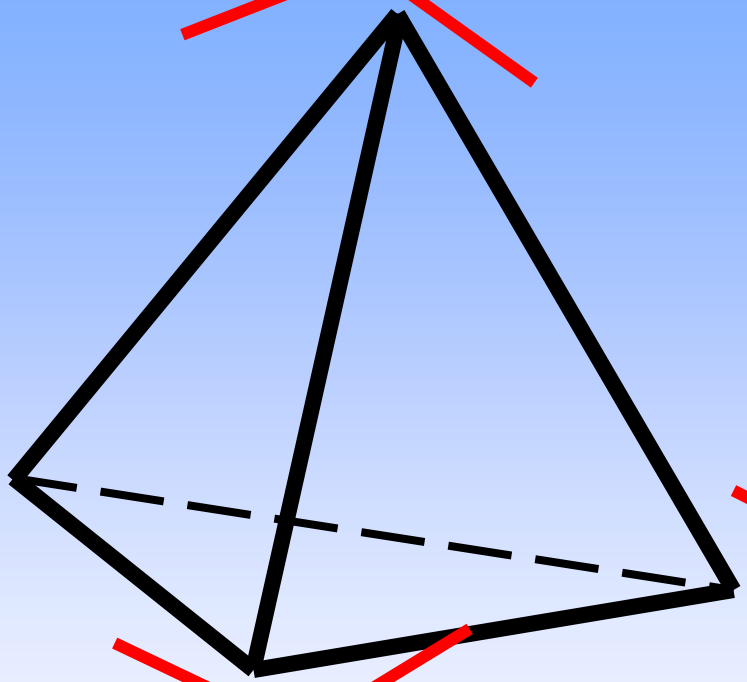
- ARD Tetrahedron Refresher
- Biochemical Reactor Refresher
- Heap Leach Technology Refresher
- Vaccination versus Medication?
- Vaccination and Medication Concepts
- Medication Case Studies
- Cost Model
- Sequatchie Test 2014

Acid Rock Drainage

Acid Rock Drainage Tetrahedron



Water

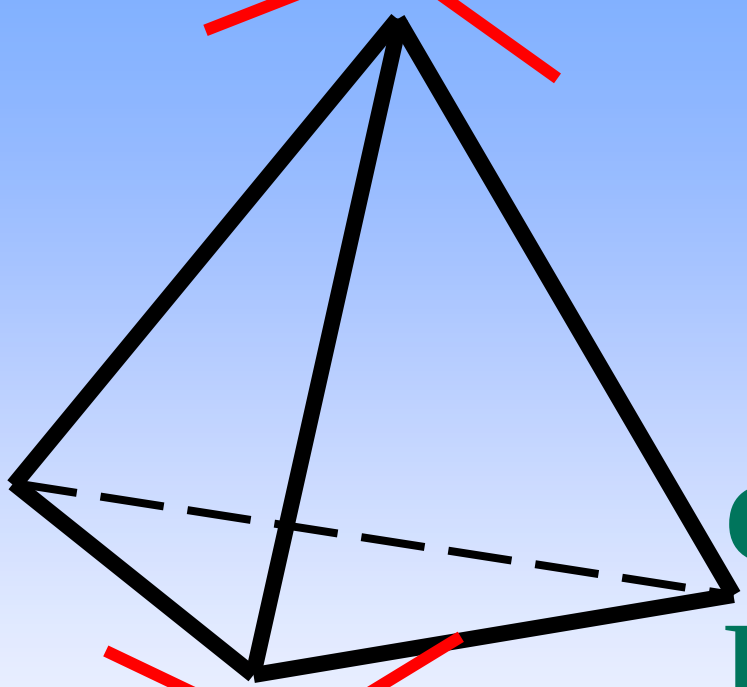
Oxidizer

(Air, Fe^{+3})

Bacteria

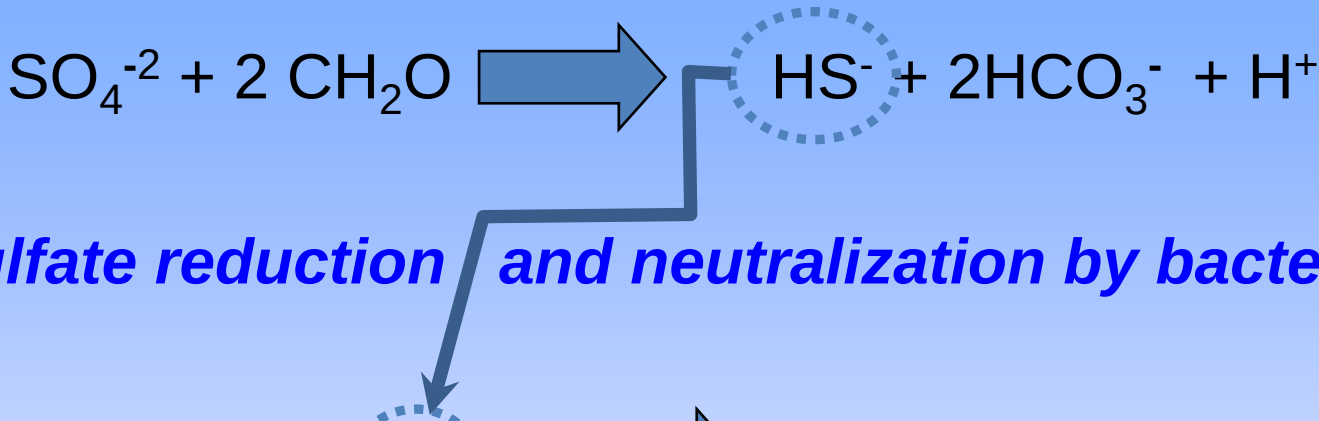
Pyrite

Acid Rock Drainage Tetrahedron

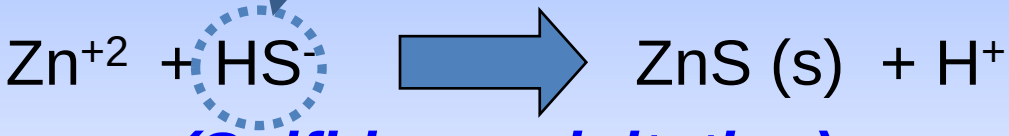


"PROBIOTIC"
PATHWAY TO WALK-AWAY

Biochemical Reactor Refresher

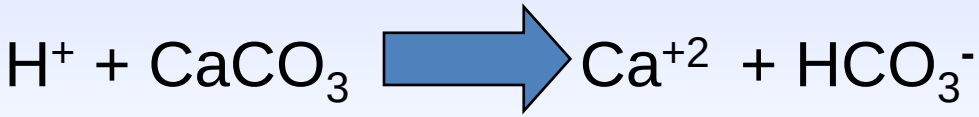


(Sulfate reduction and neutralization by bacteria)



(Sulfide precipitation)

REDUCING/ ANAEROBIC CONDITIONS



(Limestone dissolution)

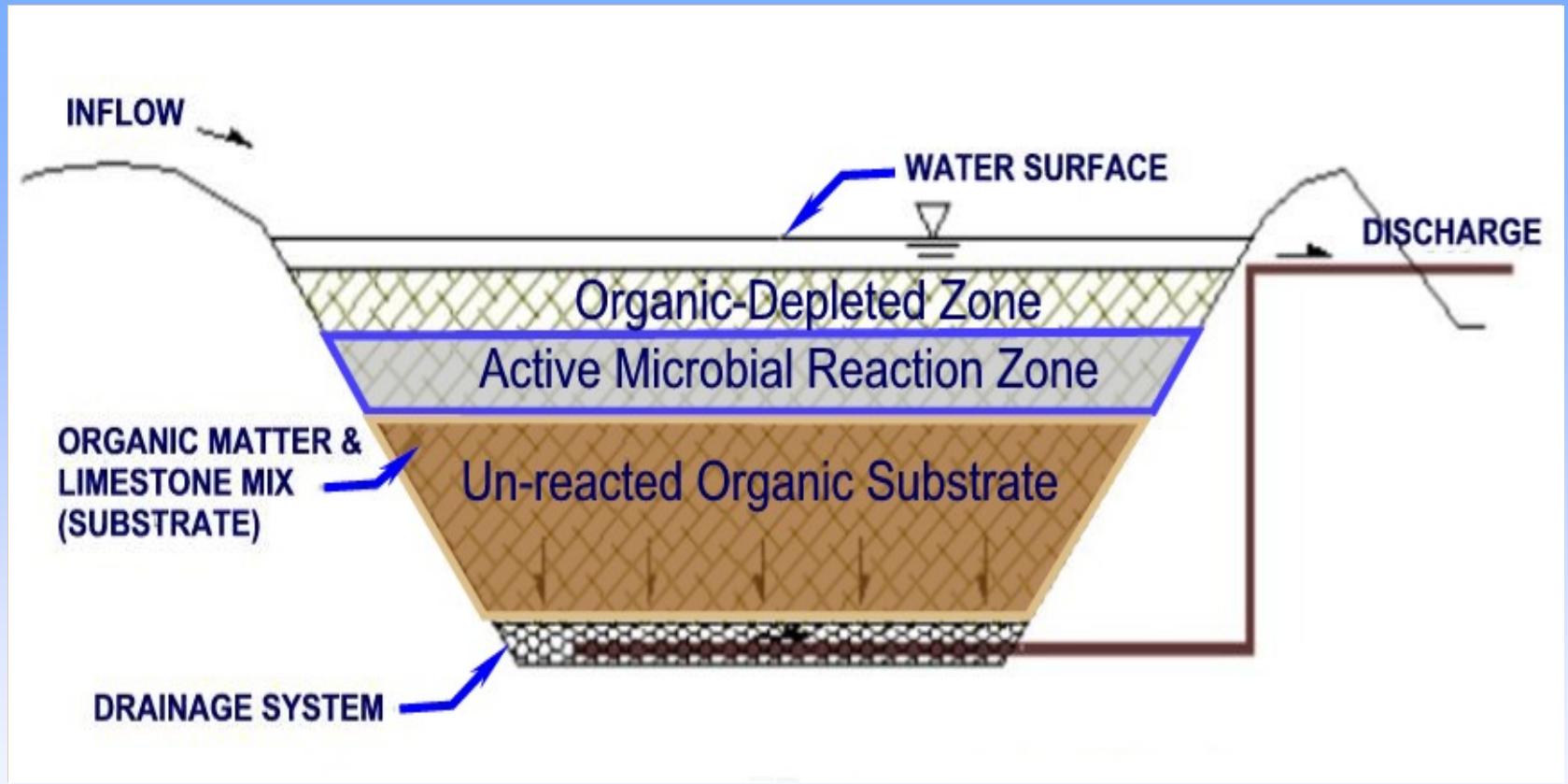
Anaerobic Biochemical Reactors (BCRs)

AKA

Vertical Flow Reactors
or
Sulfate Reducing Bioreactors (SRBRs)

Aluminum and heavy metal removal, selenium removal, de-nitrification, pH adjustment, alkalinity & hardness addition

Anaerobic Biochemical Reactors (BCRs)

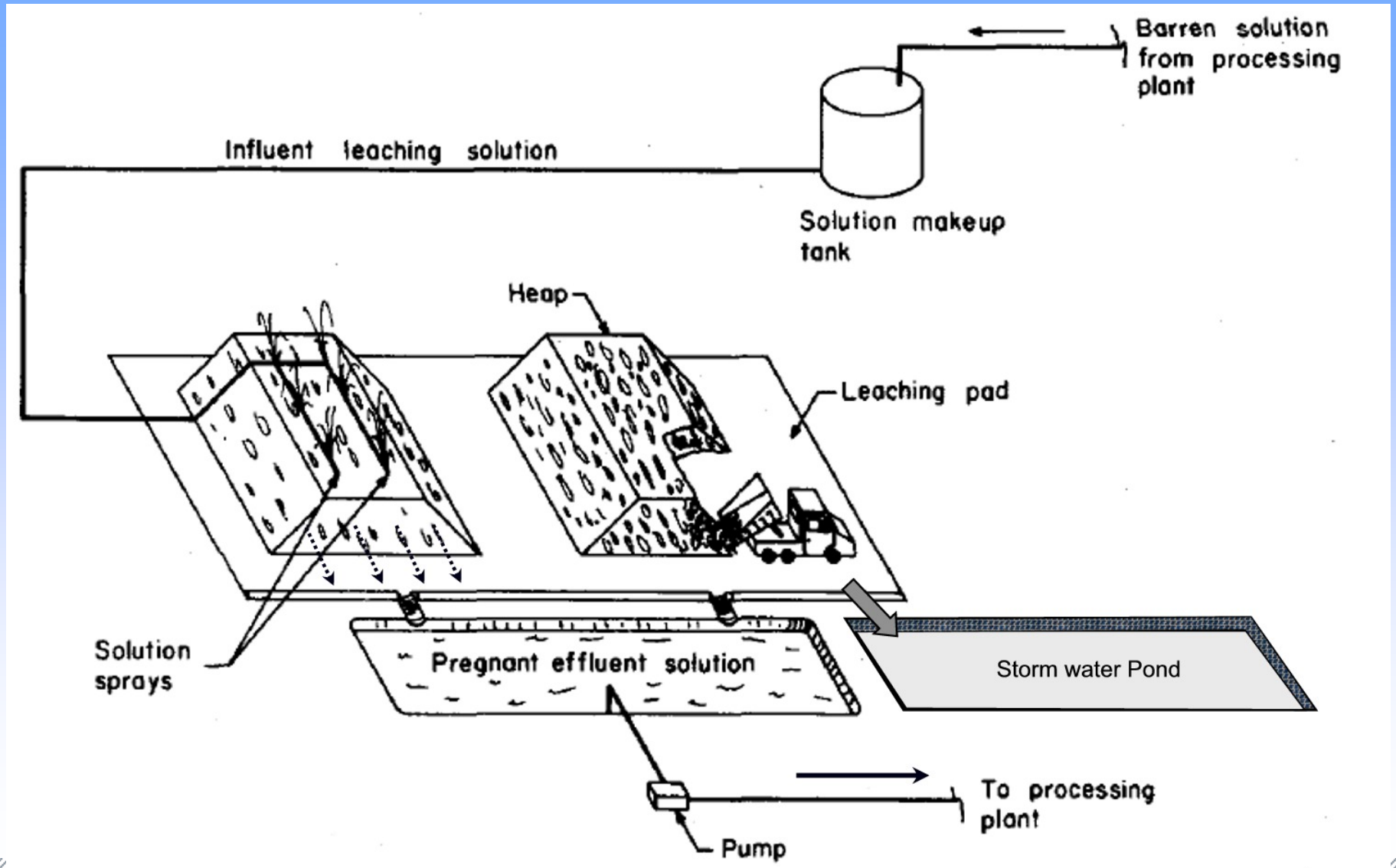


PLANTS ARE NOT REQUIRED FOR A BCR

BCR Effluent Characteristics

- Dissolved organic carbon (measured as BOD or total organic carbon [TOC])
- Bicarbonate alkalinity
- Reducing oxidation reduction potential (ORP) of – 100 mv or less
- Low dissolved oxygen [DO] (<1 mg/L)
- Dissolved sulfide ion, and
- Dissolved manganese

Heap Leach Technology



Barren Solution Delivery

- Drip Emitters

- Wobbler Sprinklers

- Reciprocating Sprinklers

- High Rate Evaporative Sprinklers

Images courtesy of Reddit.com, gtghydroponics.com, ebay, & bradshawsupply.com

Heap Leach Plumbing Layout

Courtesy of Senninger.com

Known Bactericides

- Sodium lauryl sulfate (SLS)
- Slow release commercial products
  – ProMac *(no longer available)*
- Alkyl-benzene sulfonate (laundry detergent is cheaper than SLS)
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids (patented)

Vaccination versus Medication?

Bactericides for Suppressing *Acidithiobacillus Ferrooxidans*

- Vaccination
- Medication
- Sequential Application or Cocktail?

Vaccination & Medication Scenarios

- Heap Leach Pads/Dump Leach Site
- Tailings Storage Facilities
- Waste Rock Repositories
- Pit Walls

Has any of these been done before?

Medication Case History #1

- **Fisher Coal Mine, PA – 1995**
  - ❑Geophysics targets 3 ARD–generating zones; seep pH was 5.5; iron 17 mg/L and higher.
  - ❑Multiple injection boreholes on a tight spacing
  - ❑Injection of 20% NaOH solution simultaneously into 12 shallow (3 m deep) boreholes with packers
  - ❑Injection of 2% sodium lauryl sulfate bactericide
  - ❑Seepage continues to be net alkaline 19 years later, bond release is reportedly imminent

Ref: Plocus & Rastogi, 1997

Medication Case History #1

- **Fisher Coal Mine, PA – 1995**

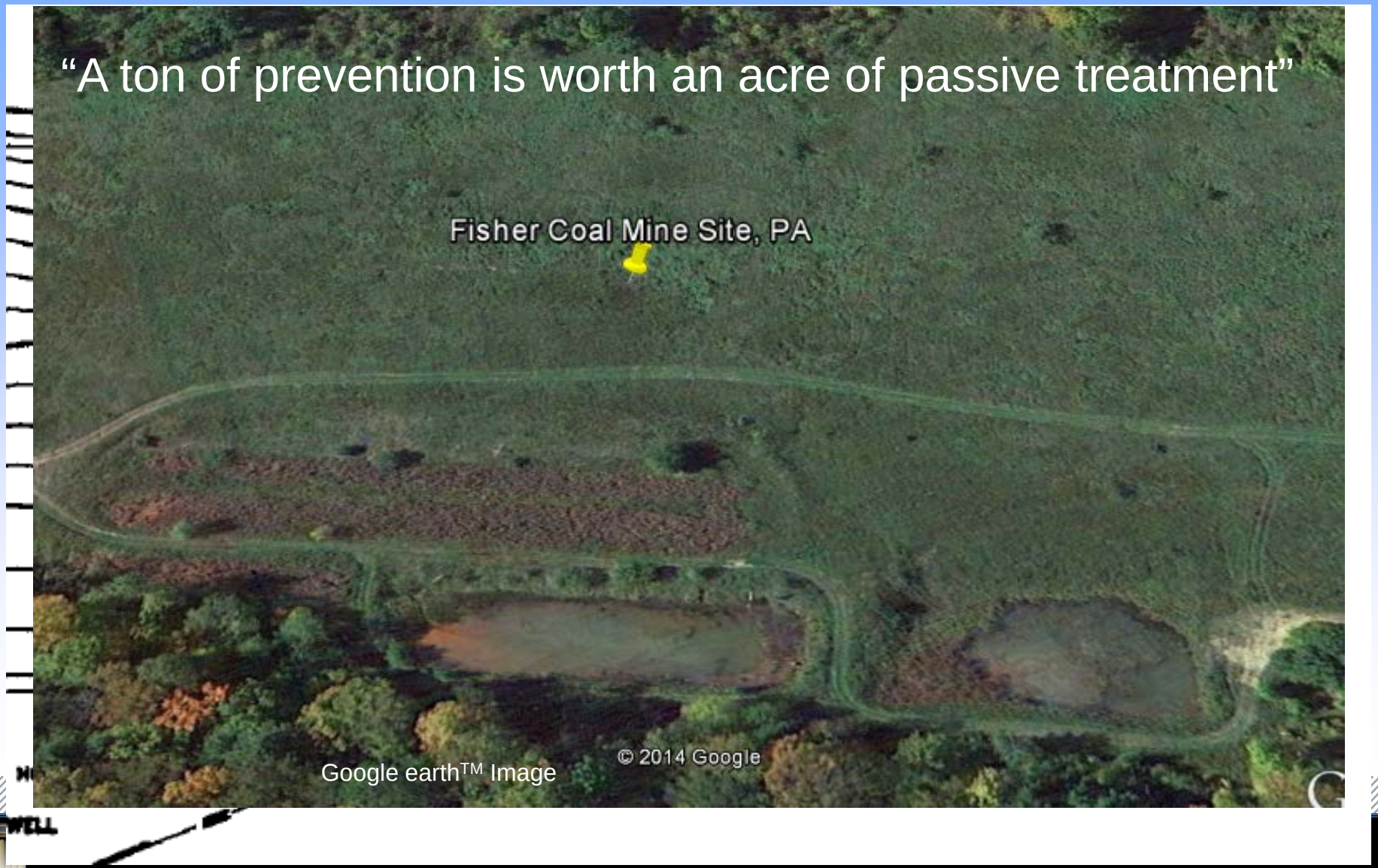
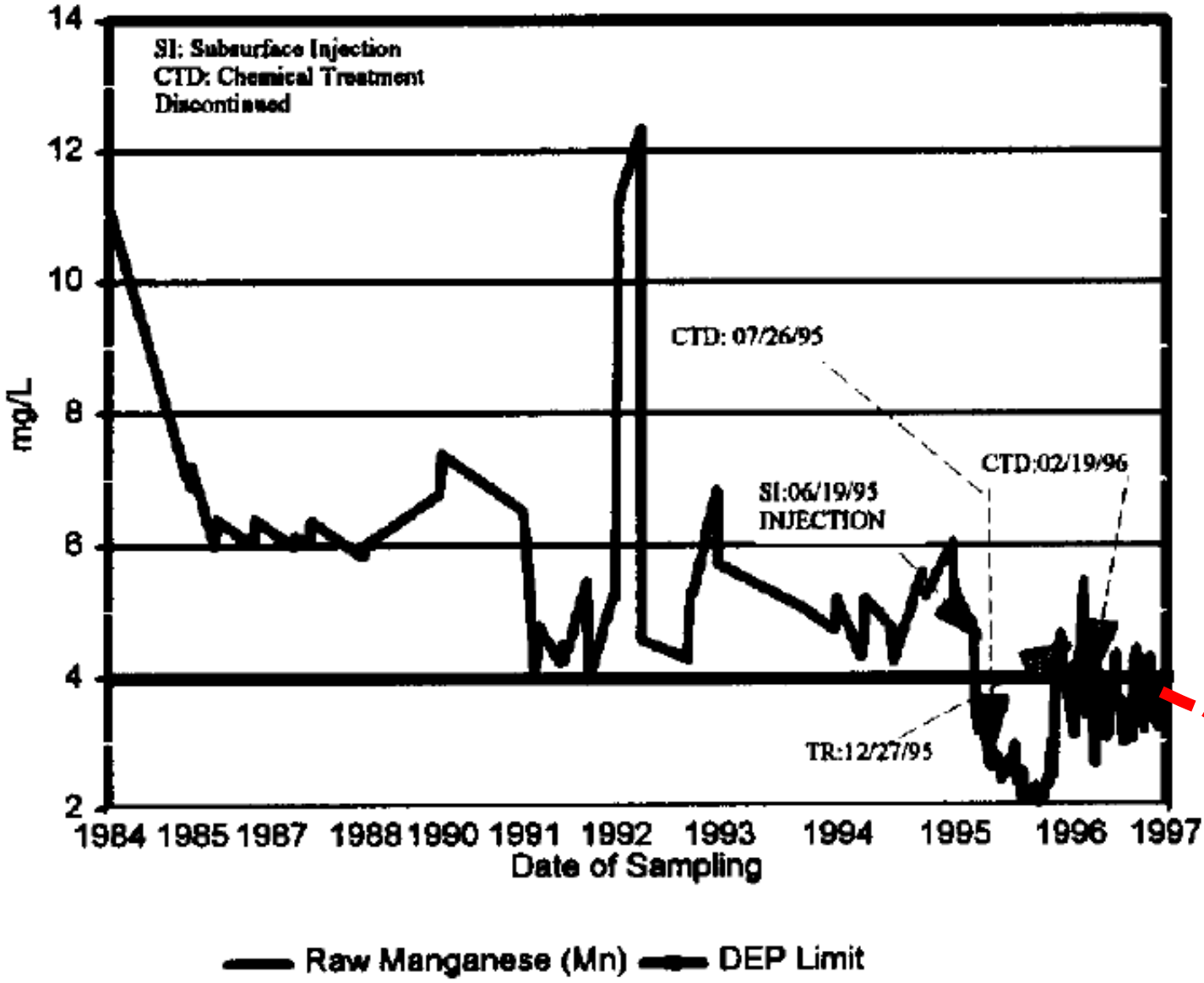


FIGURE - 6

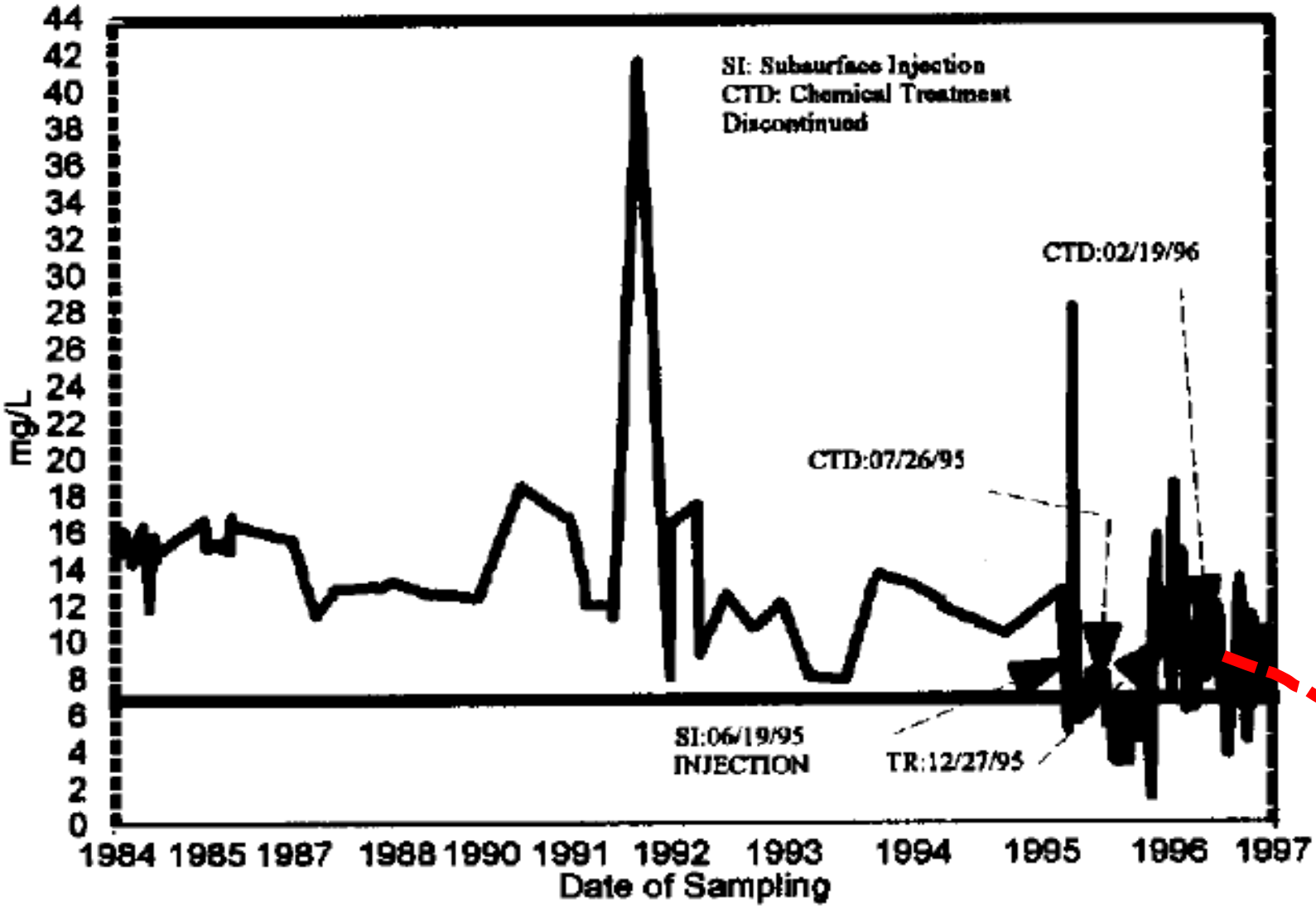
Raw Seep Manganese Concentration



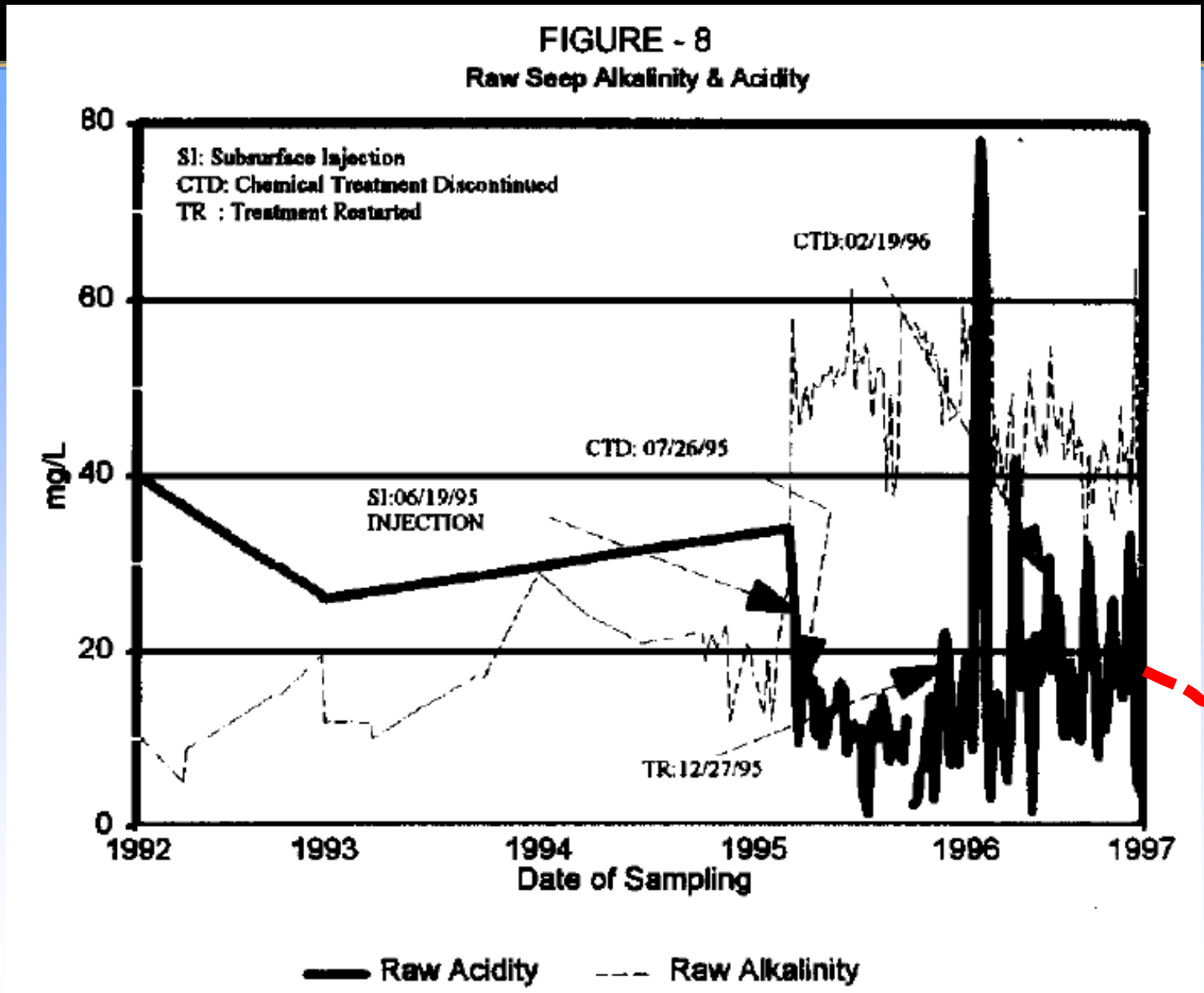
Plocus & Rastogi, 1997

FIGURE - 7

Raw Seep Iron Concentration



Plocus & Rastogi, 1997



Plocus & Rastogi, 1997

Fisher Mine Medication Case History #1

WHY DOES IT STILL WORK – 19 YEARS LATER?

1) The initial "flooding" injection of caustic neutralized the residual acidity in the mine waste so that the subsequent application of bactericide was "protected" from chemical attack;
2) The bactericide solution (2% sodium lauryl sulfate) would have followed the preferential pathways established during the stage 1 injection of caustic to inhibit the activity of the acidophilic community; and
3) The well-established revegetated surface of the site provided a steady supply of bacteria inhibiting organic acids (and continues to do so) which appears to have suppressed the "reinfection" of the site that would have otherwise occurred.

Medication Case History #2

- **Sequatchie Coal Mine, TN – 2007 Western Research Institute**
  - Geophysics used to target ARD
  - Two doses - drip application of **waste milk** and biosolids (as inoculant)
  - Seepage reportedly net alkaline after seven years.
  - Patent issued January, 2012
  - Check out ITRC website
  - **Plans to conduct follow up research (summer 2014).**

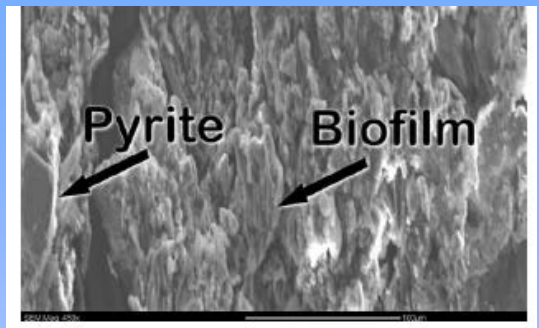


Fig. 6 Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (*ES*) and 5× the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing all the SO_4^{2-} in the microcosm. This image was taken at ×450 magnification with a scanning electron microscope

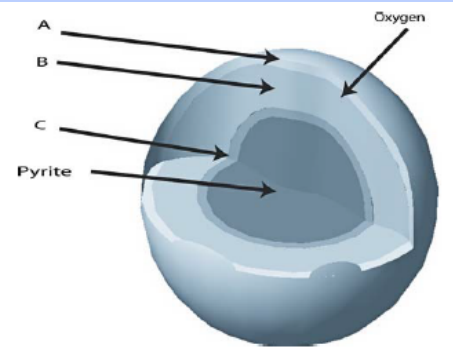


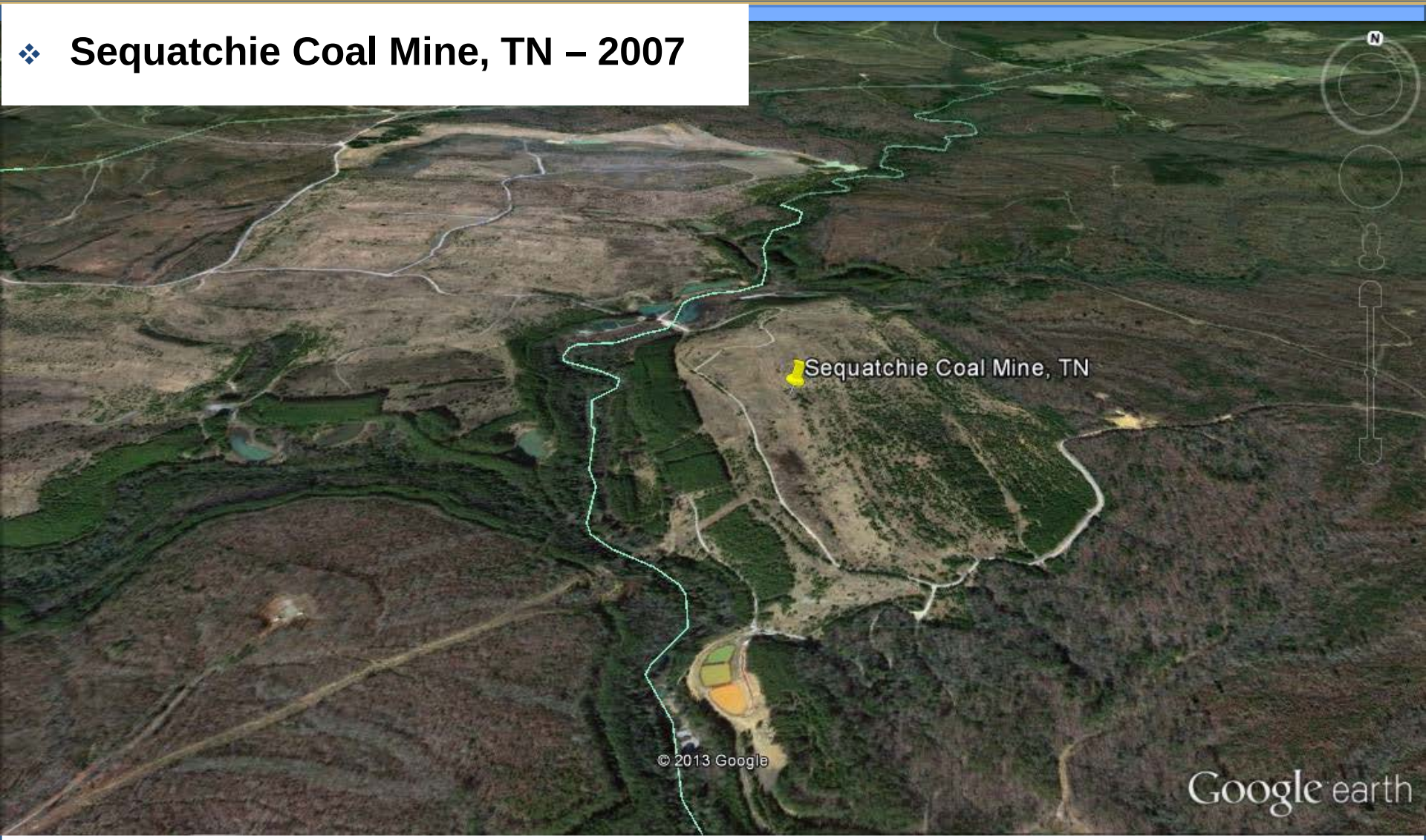
Fig. 7 Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of aerobic and facultatively anaerobic bacteria that consume oxygen (O_2) diffusing through the biofilm from overlying water. Layer C is an anaerobe-dominant layer containing sulfate reducing bacteria and other facultative anaerobes; therefore, oxygen diffusion to the pyrite and generation of acid mine drainage is prevented

Ref: Jin et al., 2007

http://www.itrcweb.org/miningwaste-guidance/cs31_sequatchie.htm

Medication Case History #2

- **Sequatchie Coal Mine, TN – 2007**



Sequatchie Site Medication Case History #2

WHY DOES IT STILL WORK – 7 YEARS LATER?

1) No formal "bactericide" in the mixture, just milk?
2) Casein in the waste milk curdles when it encounters pH <4.6 conditions
3) This might create a *"heat-seeking missile"* effect that is pyrite-surface selective
4) Curdled milk is a protein, which is slow to degrade and would provide a long-term electron donor source for heterotrophic bacteria
5) Revegetated surface of the site provides a steady (sustainable) supply of acidophile-inhibiting organic acids. (Similar to Fisher Site)

Similarities and Differences

BCR Effluent would behave more like waste milk than the sequential approach by Plocus & Rastogi at the Fisher Mine

BCR effluent may oxidize more quickly when it encounters acidic conditions on a pyrite grain surface to form a biofilm

BCR effluent-derived biofilm wouldn't contain much long-lived protein

BCR effluent will probably contain manganese, which should form abiotic coatings (over any surface) deeper in the mine waste column

Application Concept: Mine Dumps

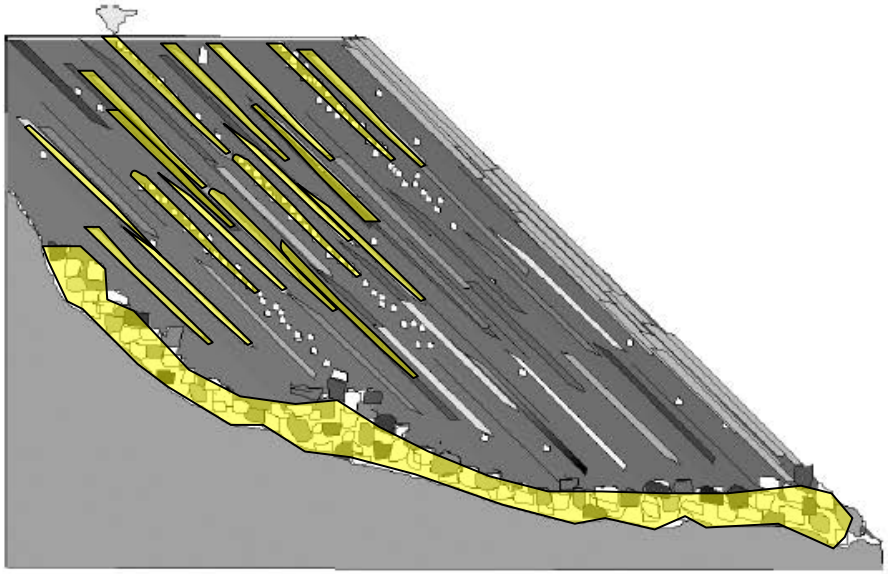
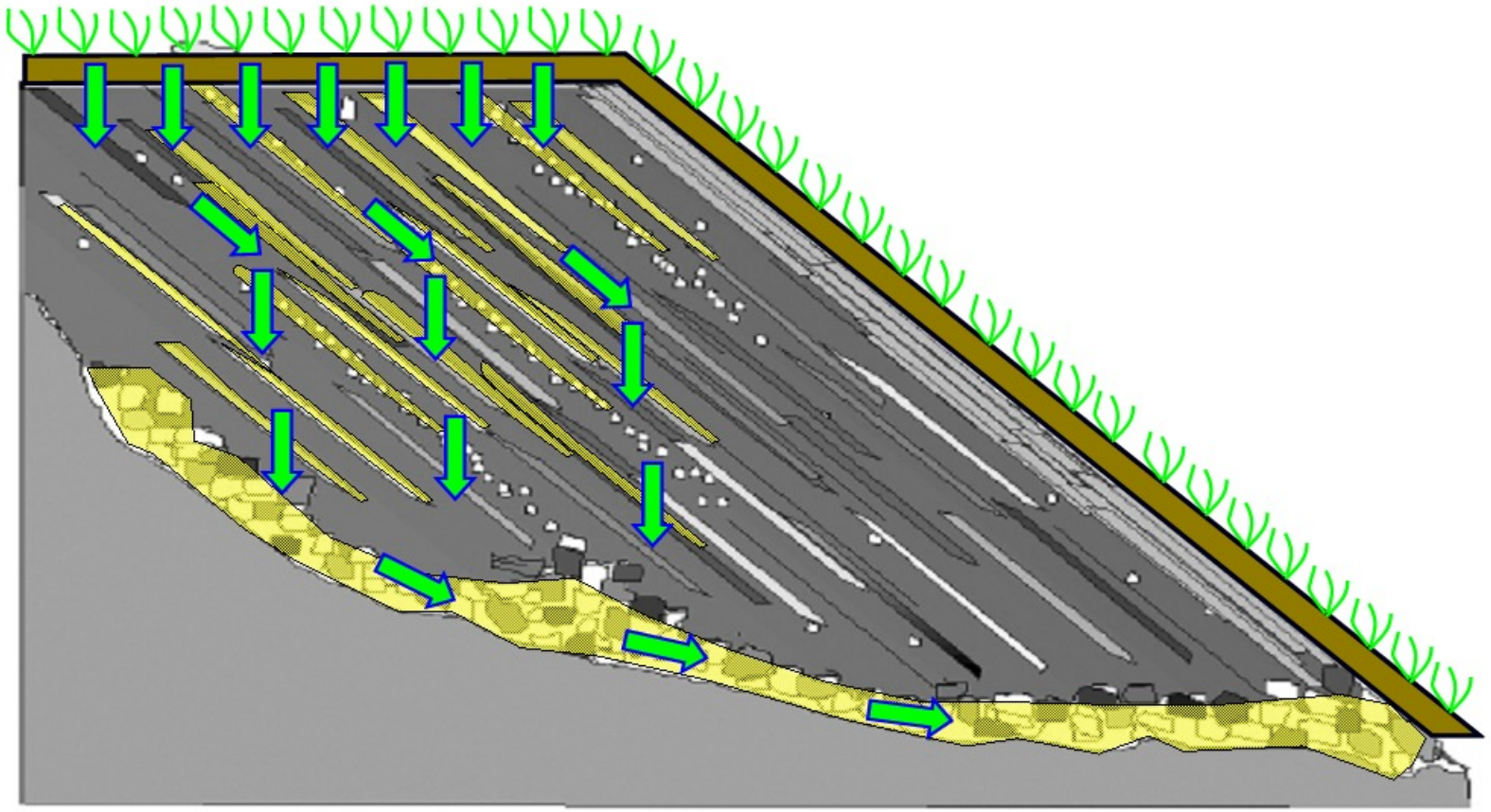


Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

After G.W. Wilson, 2008

Application Concept: Mine Dumps



Preliminary "Medication" Cost Model

- Waste Rock Repository – 100 acres divided into 20-acre application zones
- Add 60 inches (152 cm) of BCR effluent for a year (34 m^3/day)
- 8 hrs/day yields about 24 gpm
- Drip row spacing of 3 ft (1 meter)

Preliminary "Medication" Cost Model

- Capital cost $14,500 converts to fixed cost of $7,200/yr.
- Operating cost $19,000/yr.
- Total drip irrigation cost: $26,000/yr. for 20 acres
- BCR effluent $0.31/$m^3$ or $4,000/yr.

Total cost of $30,000/annum or $1,500/acre treated ($3,700/ha)

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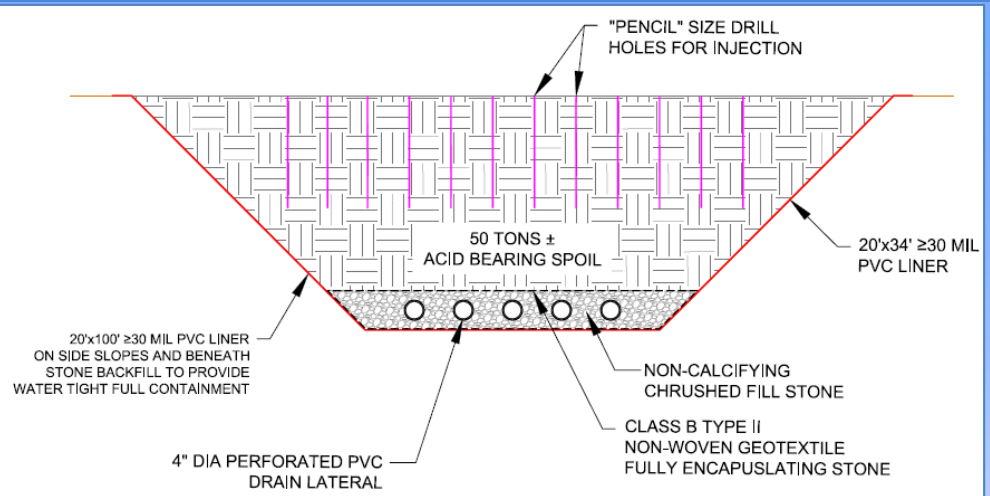
COMPARE TO PERPETUAL TREATMENT

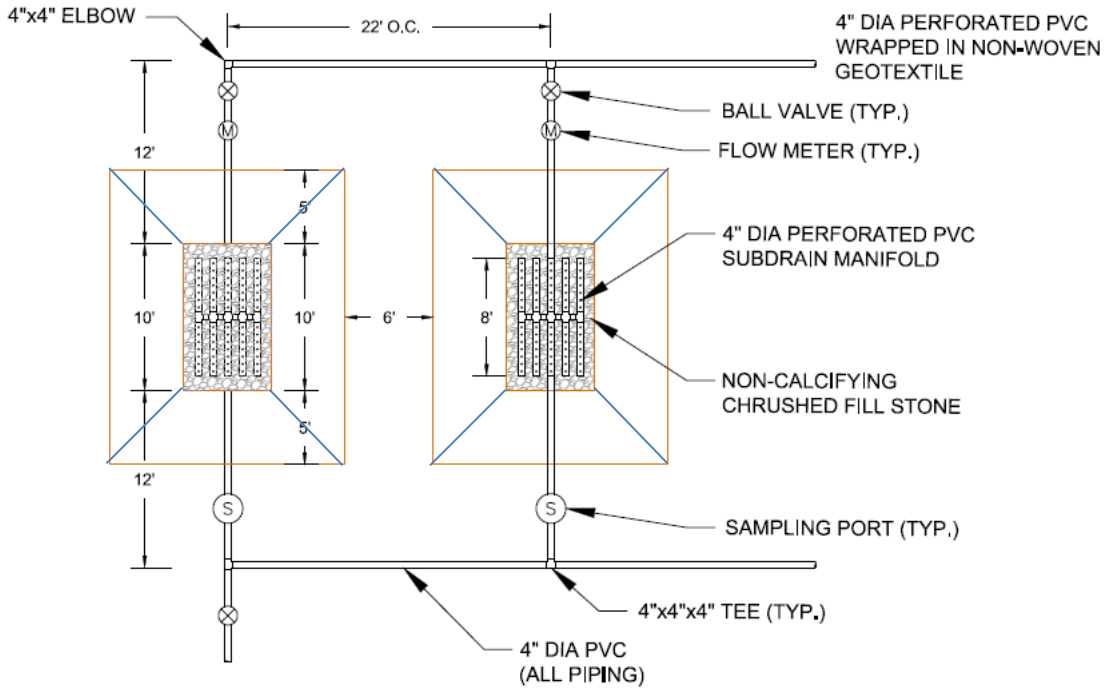
Sequatchie Mine Test Program 2014

Sequatchie Mine Test Program 2014

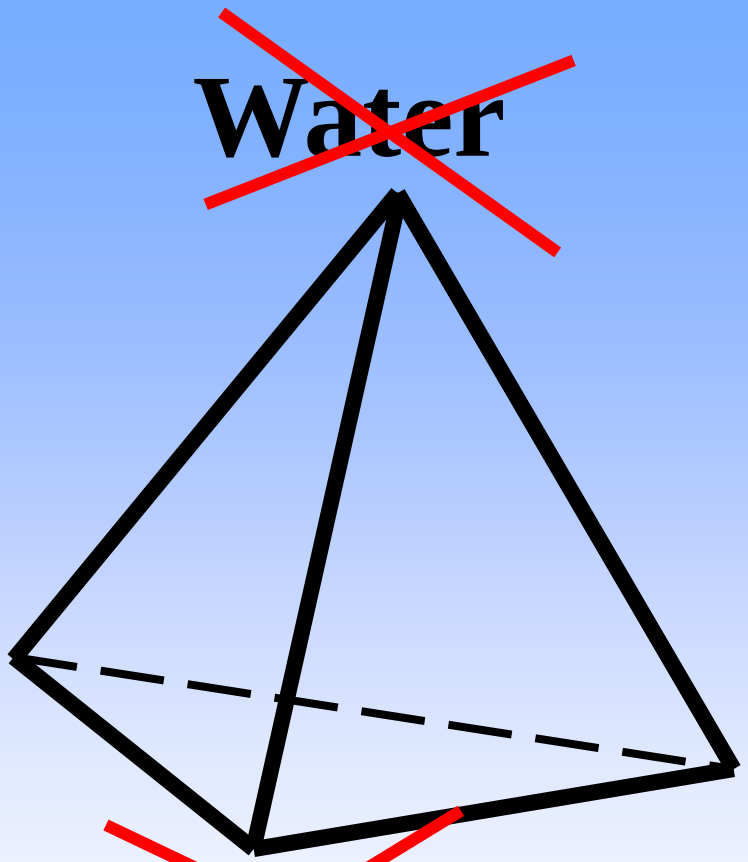


UNDERDRAIN SECTION VIEW

NOT TO SCALE



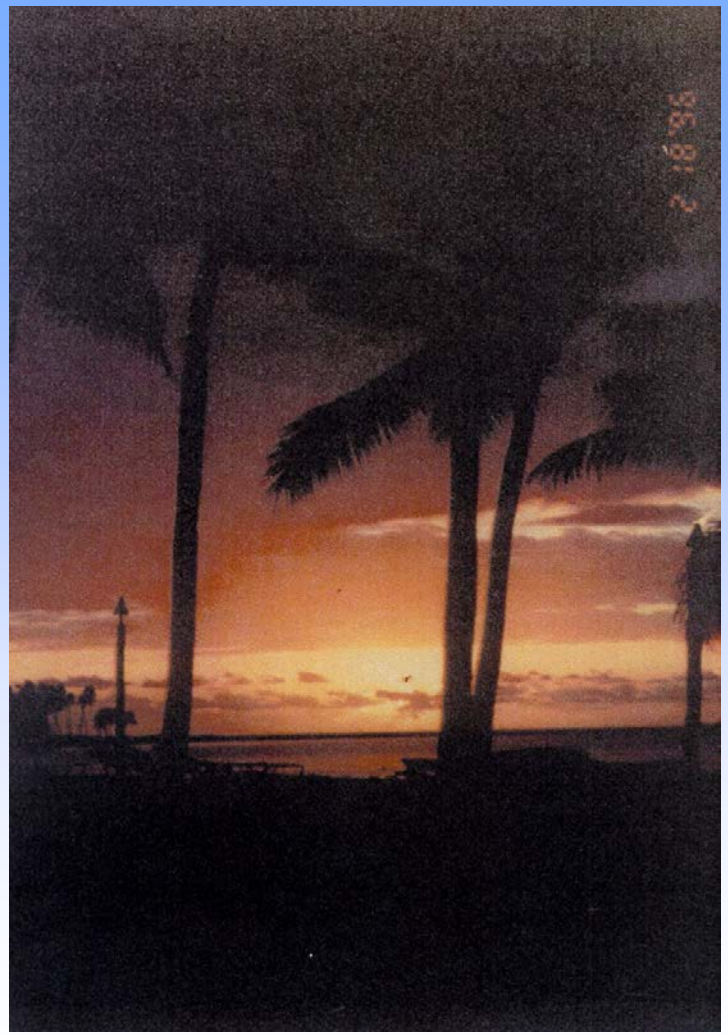
In Addition to Geochemical & Physical Controls…



Good Bacteria fed with Organic Matter

"PROBIOTIC" PATHWAY TO WALK-AWAY

Thank You



Questions?

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