# An Innovative Method for Mitigating Impacts from Acid-Producing Rock

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# Acid Rock Drainage

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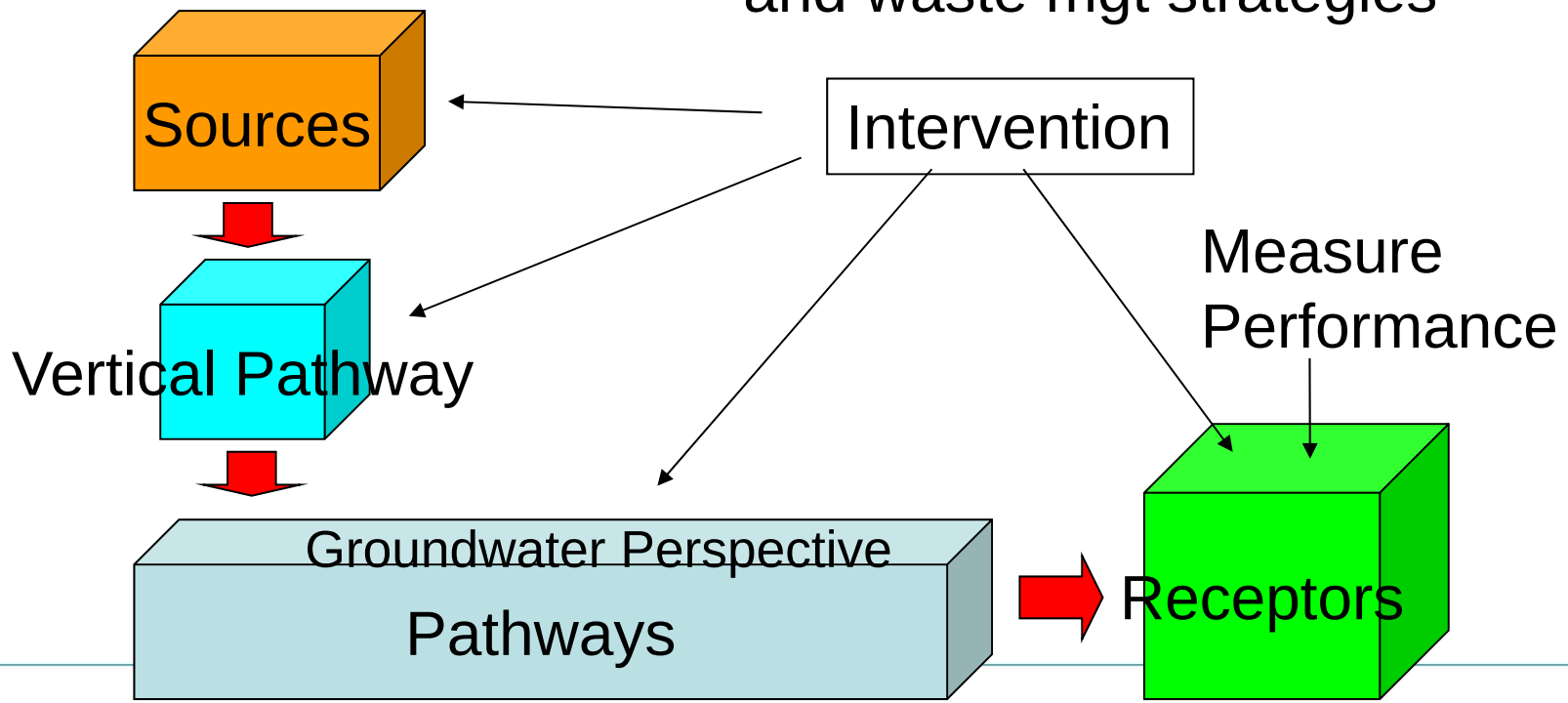
# Overview of Best Practice Methods

**REF: GARD Guide 2010**
***www.gardguide.com***

Early avoidance of ARD problems is a best practice technique that is integrated into mine planning, design and waste mgt strategies

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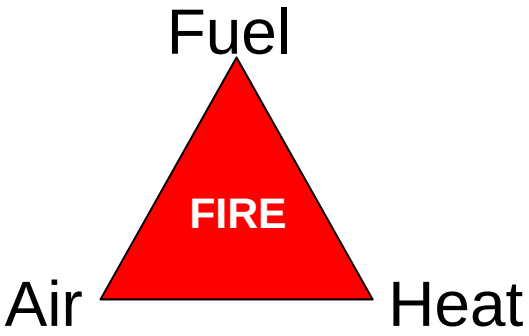
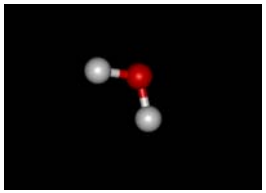
# Acid Rock Drainage Tetrahedron

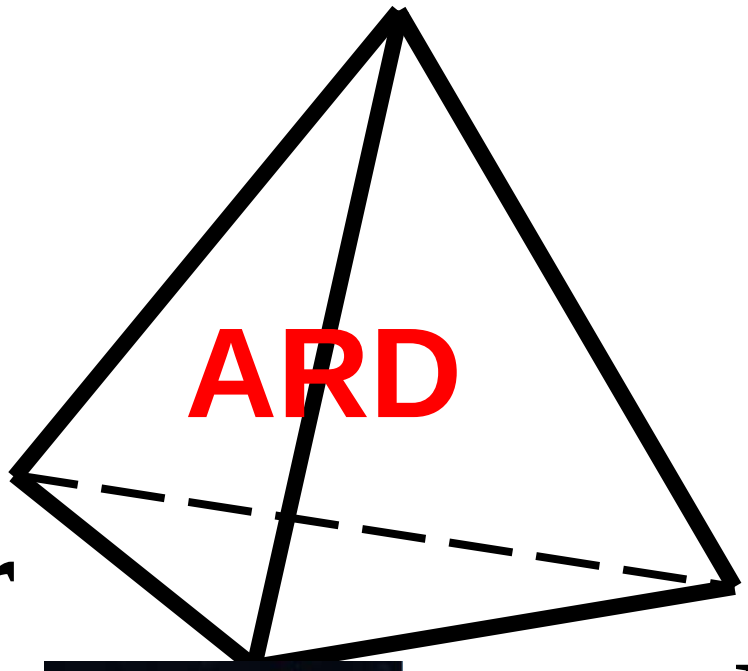



**Water**



**Oxidizer**

**(Air, $Fe^{+3}$)**




**Bacteria**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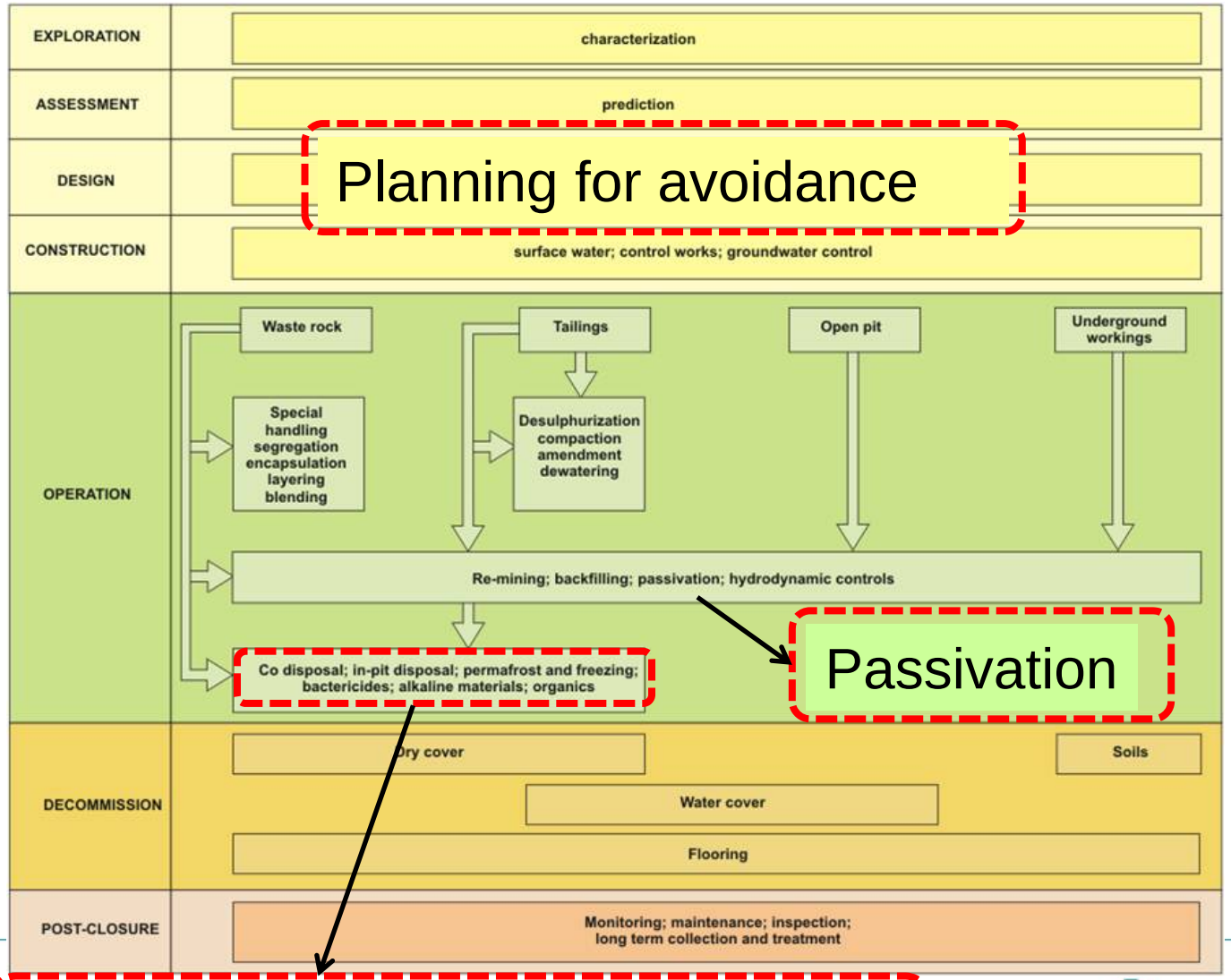
# ARD Mitigation Framework

**REF:**
**GARD Guide 2010**

**Also see:**

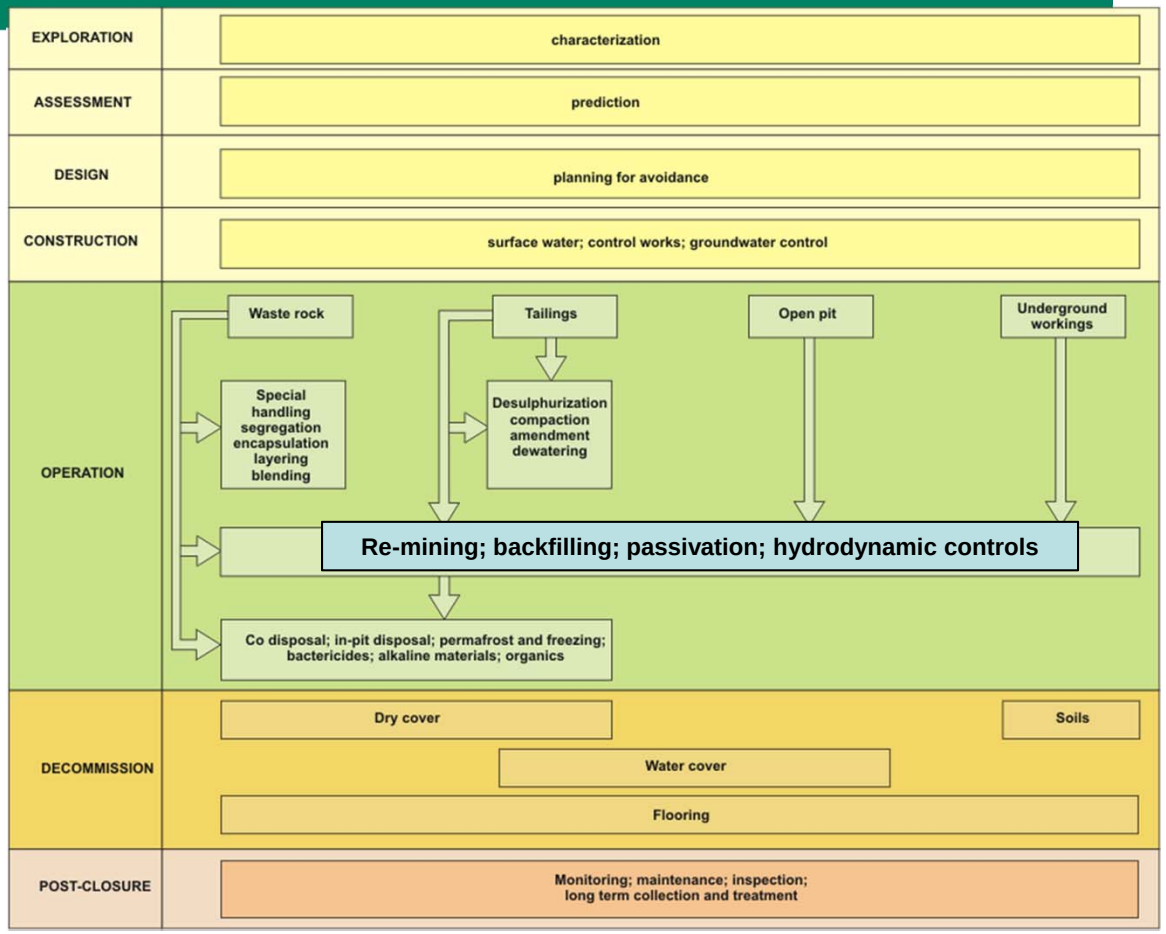
***Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania; Brady et al., 1998***




**Co-disposal, in-pit disposal… bactericides, alkaline materials, organics**

# Best Practice Methods - Avoidance

- Avoidance
  - Special handling methods
    - Incorporate into mine plan
    - Segregation
    - Tailings desulphurization
    - Compaction and conditioning
    - Encapsulation and layering
    - Blending
    - Co-disposal
    - Permafrost and Freezing

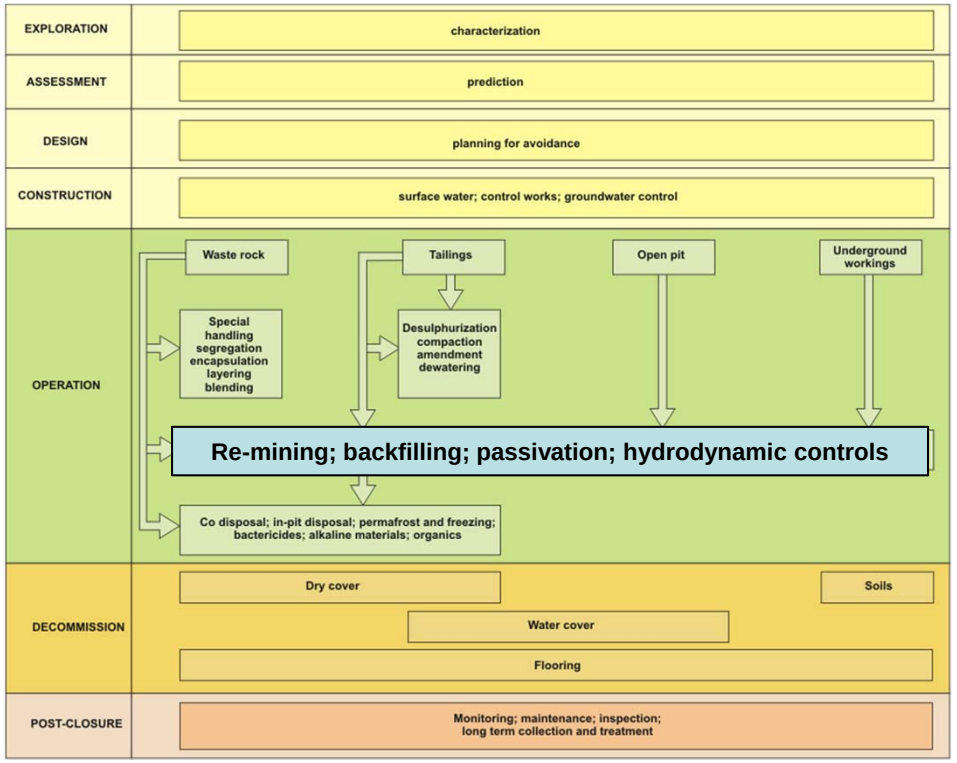



**What about *abandoned* mines?**

**REF: GARD Guide 2010**

# Best Practice Methods (Decommissioning)

- Dry Cover Methods
  - Soil
  - Alkaline
  - Organics
  - $ynthetics
  - Gas barriers
  - Vegetation
  - Landform design
- Water Cover Methods
  - Subaqueous disposal
  - Partial water cover
  - Wetland covers
  - Attenuation
  - Stream flow regulation
  - Water recycle and reuse




**REF: GARD Guide 2010**

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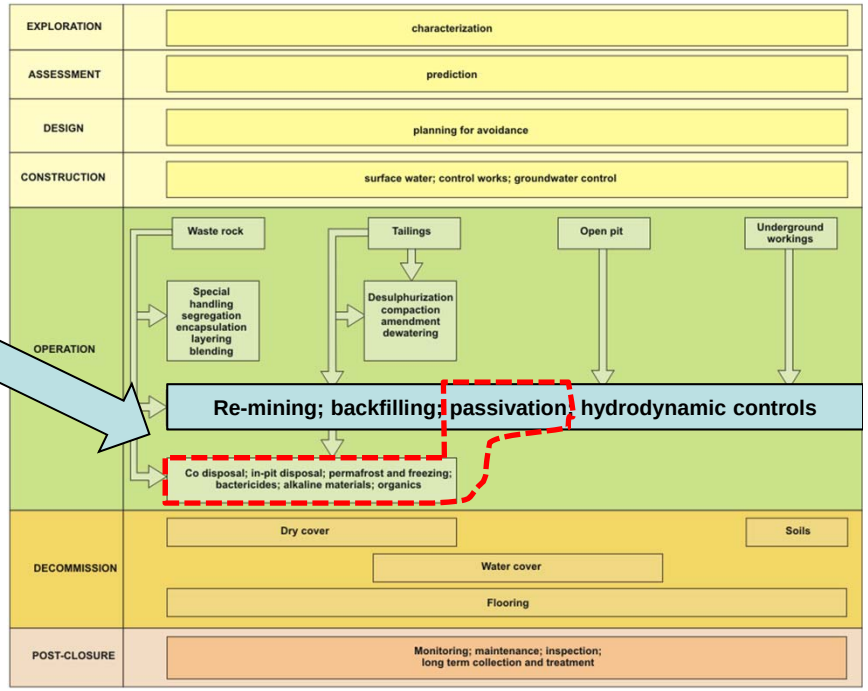
# Best Practice Methods- Passivation

- Additions and Amendment Methods
  - Passivation
  - Alkaline materials
  - Organics
  - Bactericides (Brady, Ch. 15)
- Water Management Methods
  - Hydrogeological & Hydrodynamic Controls
  - Dewatering
  - Diversion
  - Flooding
  - Seals

???




**How do you to implement these methods at abandoned mines?**

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# THE REAL PROBLEM: A Medical Analogue

ARD is a global **bacterial infection**.

There are plenty of geo-antibiotics available but the current situation is akin to the patient taking a shower with Tums dissolved in orange juice - not very effective or practical.

What's needed is a mining-analogue to an I-V drip of tetracycline and/or oral antibiotics.

And then there's the question: Do we need to **Vaccinate** or **Medicate**?

**What is currently available in the ARD prevention "pHarmacy"?**

# Known bactericides

- Sodium lauryl sulfate (EPA-endorsed)
- Alkyl-benzene sulfonate (laundry soap)
- Waste milk (bacteria out-complete *acido-thiobacillus)*
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids

Note: We need to consider the *physics* of delivering and distributing a weak bactericide solution into a porous, unsaturated medium (it's been done, but it wasn't easy)

# Cheap alkalinity (~~acidity~~)

- Limestone (quarried) – crusher fines?
- Dolomite
- Lime kiln dust or cement kiln dust
- Steel slag
- Sodium bicarbonate

Note: We need to consider the *physics* of delivering and distributing a solid into a porous unsaturated medium

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# Cheap organics (~~oxygen~~)

- Sawdust (the finer, the better)
- Paper (newsprint, office waste [shredded])
- De-inking residue
- Biosolids
- MicroCg™, Lactoil™, others?

Note: We need to consider the *physics* of delivering and distributing a solid into a porous, unsaturated medium

# Passivation coatings (~~oxygen~~)

- Keeco Mix (micro-silica)
- Potassium permanganate (Glen Miller, UNR)
- Oil and latex based paint
- Potassium humate (commercial agricultural amendment)
- Others?

Note: We need to consider the *physics* of delivering and distributing a coating into an unsaturated porous medium

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# One Particular Problem

## Treating existing waste rock dumps

- Deliver bactericides without complete flooding of waste rock mass
- Focus the delivery of alkalinity in the “hot zones”
- Deliver organics in hot zones and without complete flooding

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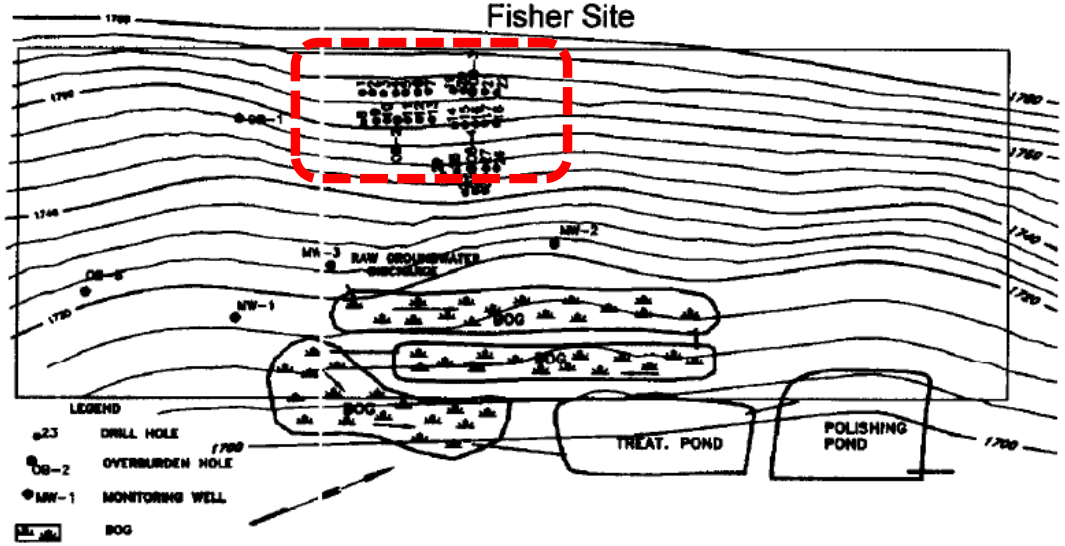
# Has it been done before?

- **Fisher Coal Mine, PA – 1995 Vapco Engineering**
  - Geophysics targets  3 ARD–generating zones
  - 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 16 years later, bond release is reportedly imminent

Figure 5 - Location of Wells on Fisher Site



# Has it been done before?

- **Sesquatchie Coal Mine, TN – 2008 Western Research Institute**
  - Geophysics used to target ARD
  - Two doses - drip application of waste milk and biosolids (as inoculant)
  - Seepage reportedly net alkaline after four years.
  - Patent issued January, 2012
  - Check out ITRC website

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

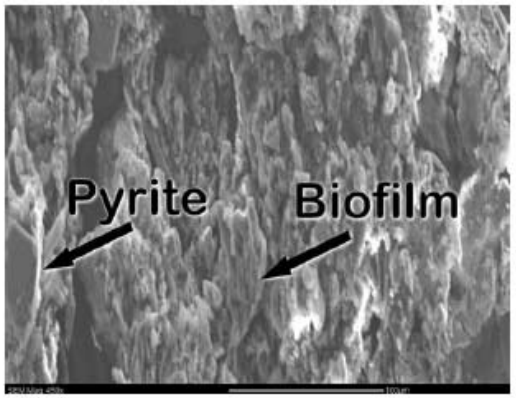



**Fig. 6** Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (*ES*) and 5× the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing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

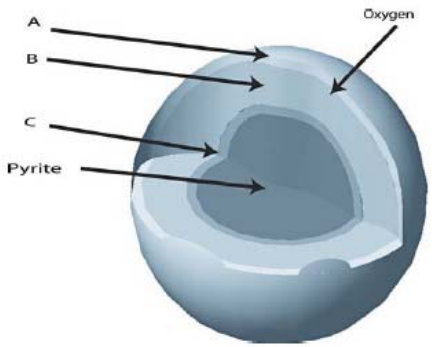



**Fig. 7** Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of aerobic and facultatively anaerobic bacteria that consume oxygen ($O_2$) diffusing through the biofilm from overlying water. Layer C is an anaerobe-dominant 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

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**THERE HAS TO BE A BETTER WAY**

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# Perhaps a better way:

## Use engineered FOAM as a delivery medium for bactericide "cocktail"

- Use waste milk (biocide) in the liquid phase
- Use sodium lauryl sulfate (bactericide) as part of the surfactant mix
- Add powdered limestone for alkalinity
- Add paper, sawdust, or **biosolids** as the organic (hoof & horn protein surfactant too)

# Perhaps a better way:

**Use engineered FOAM as a delivery medium for bactericide "cocktail"**

*This process is very similar to pressurized grouting, only the grout mass is mostly gaseous, engineered to be temporary, and designed to deposit a coating of active ingredients*

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# Foam Characteristics (Think shaving cream – a LOT of it)

Two-phase “colloid”, the gas phase is separated by a liquid phase

Foam can contain a third phase – ***suspended solids***

- ❑“Dry” foam (e.g., shaving cream)
- ❑“Wet” foam (e.g., hand soap)

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# Adding pHoam™ containing powdered limestone to gravel in the lab

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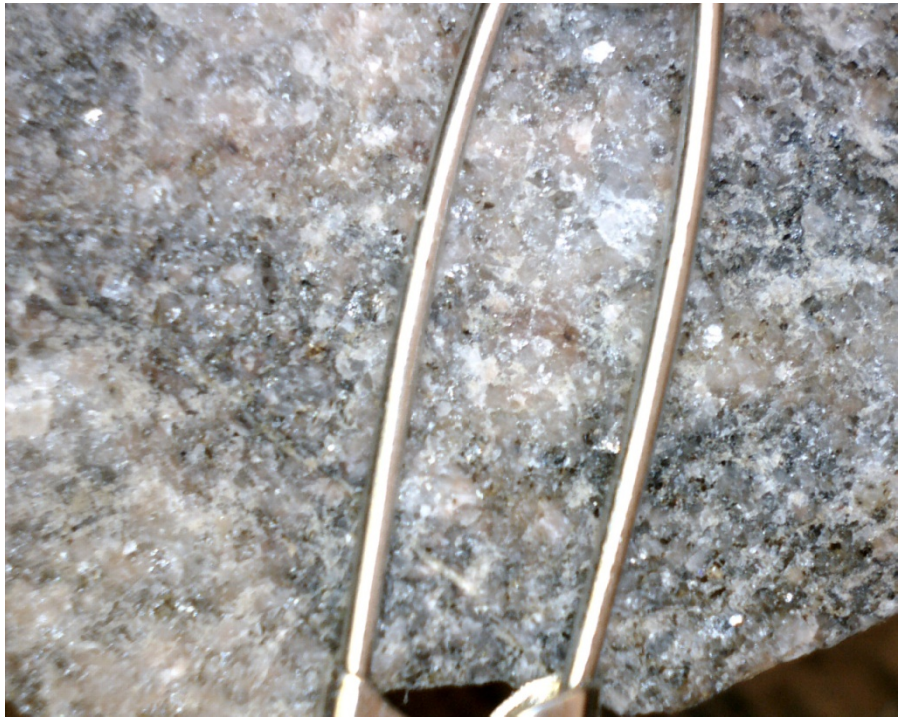
# Recent Experiments in the Laboratory



Limestone-Coated Gravel

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# Recent Experiments in the Laboratory

Garden hose tremmie pipe

# What's the difference between foam and pHoam™ ???

**pHoam™** is a mixture of traditional foam plus one or more "active ingredients" that ***induce*** a desirable biological, geochemical, or process-related reaction

**or**

Foam + active ingredients that suppress an undesirable reaction.

# Some Potential Application Concepts

| Vaccination (Prevention) | Medication (Mitigation) |
|---|---|
| **Waste rock dumps at active mines** ("sterilize" ARD rock by the truckload before it is placed in the dump) | **Small-scale** "dog hole" **abandoned underground mines** that produce ARD |
| **Active coarse coal refuse piles** (sterilize refuse by adding a "wet" pHoam™ in the feed hopper of a conveyor belt) | **Waste rock dumps or coarse coal refuse facilities at abandoned mines** (even if they are capped) |
| **Active tailings storage facilities** (sterilize the cycloned coarse tails in the embankment – the material most likely to form ARD before capping and revegetation) | **Abandoned underground mine stopes** (use geophysics for targeting and inject pHoam™ through bore holes) – use mine fire/foam equipment? |
| **Active underground mine stope** backfill materials | **Backfilled pits** (coal or metal) that are poorly capped |

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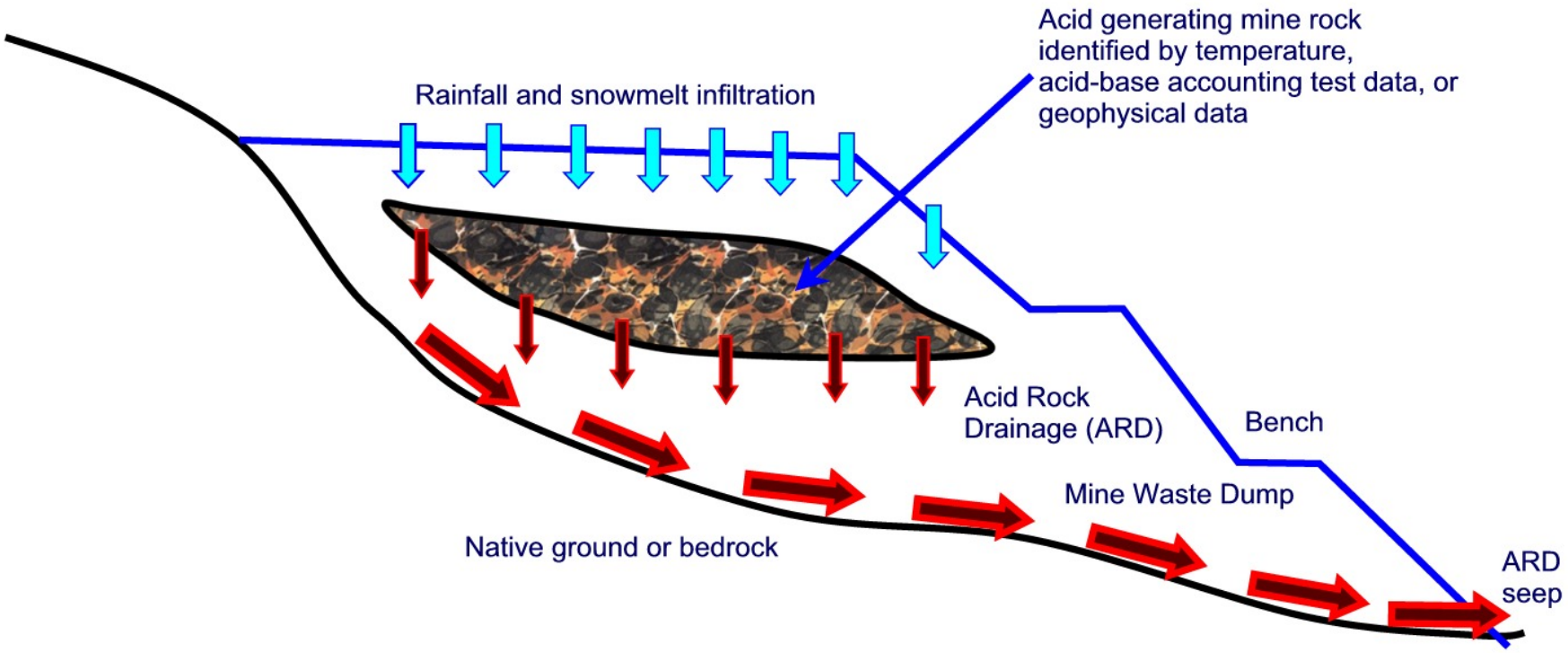
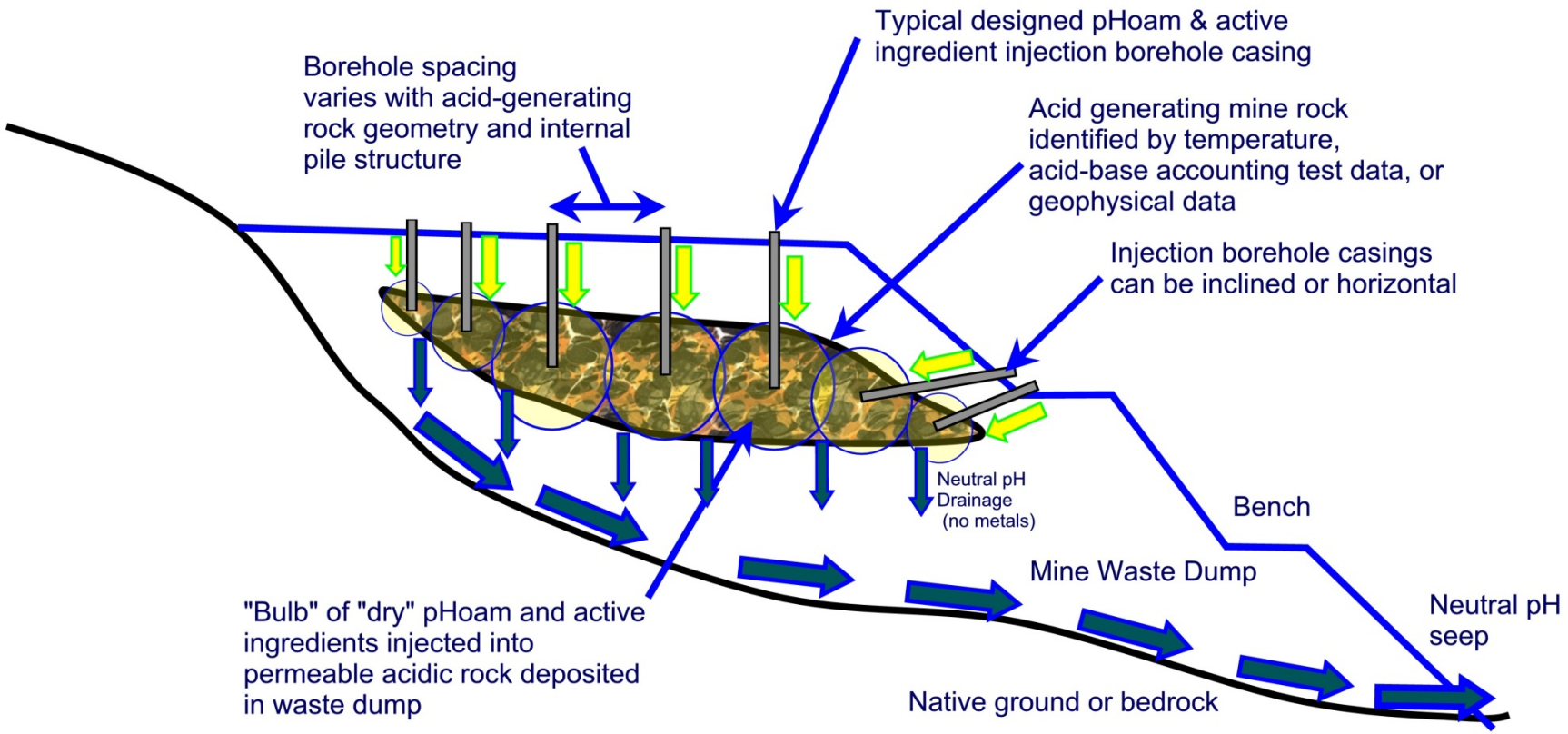
# Application Concept: Mine Dumps




Waste Rock Dump = Big Humidity Cell

# Application Concept: Mine Dumps




Waste Rock Dump

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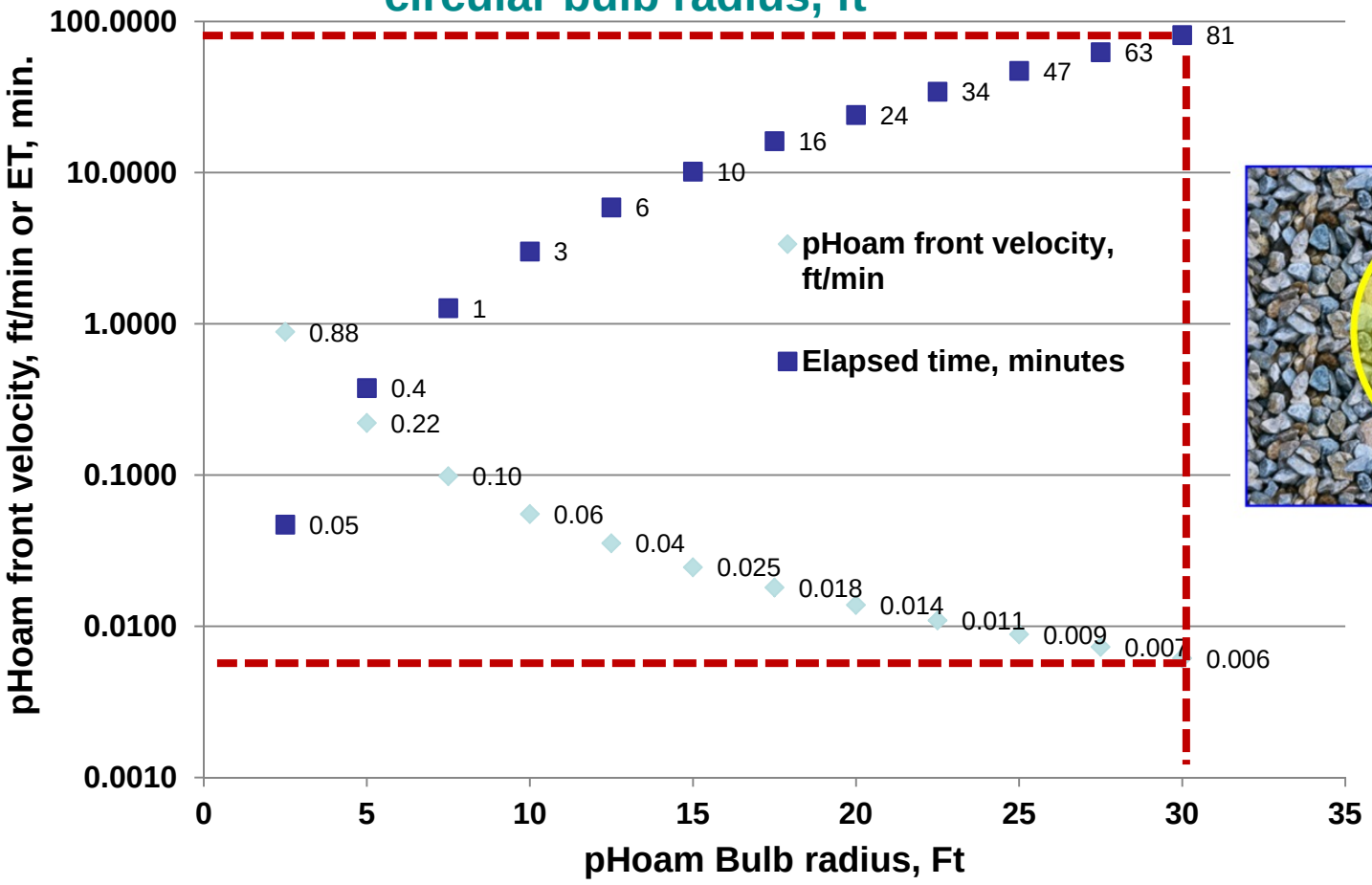
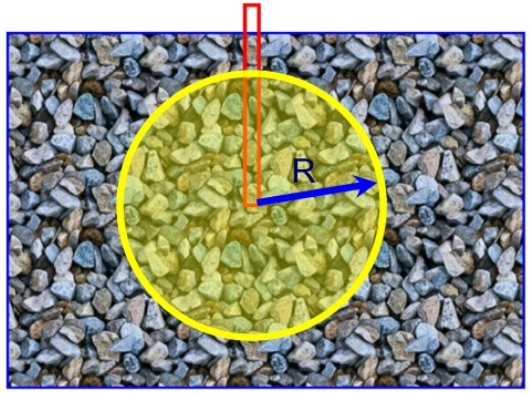
# pHoam injection kinetics - theory

## Theoretical pHoam front velocity, ft/min vs. circular bulb radius, ft




*Assumed injection conditions: 29% voids, pHoam injected at 3.7 cy/min (100 cfm)*

# Application Concept: Mine Dumps

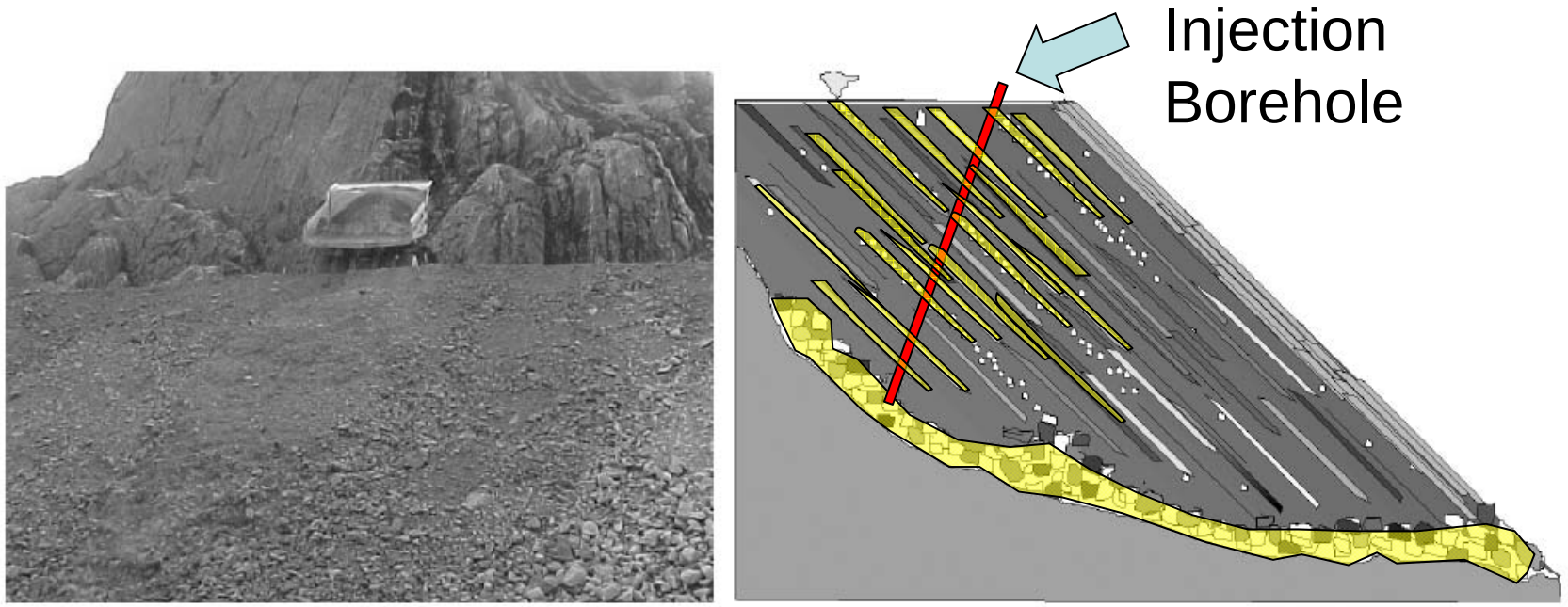


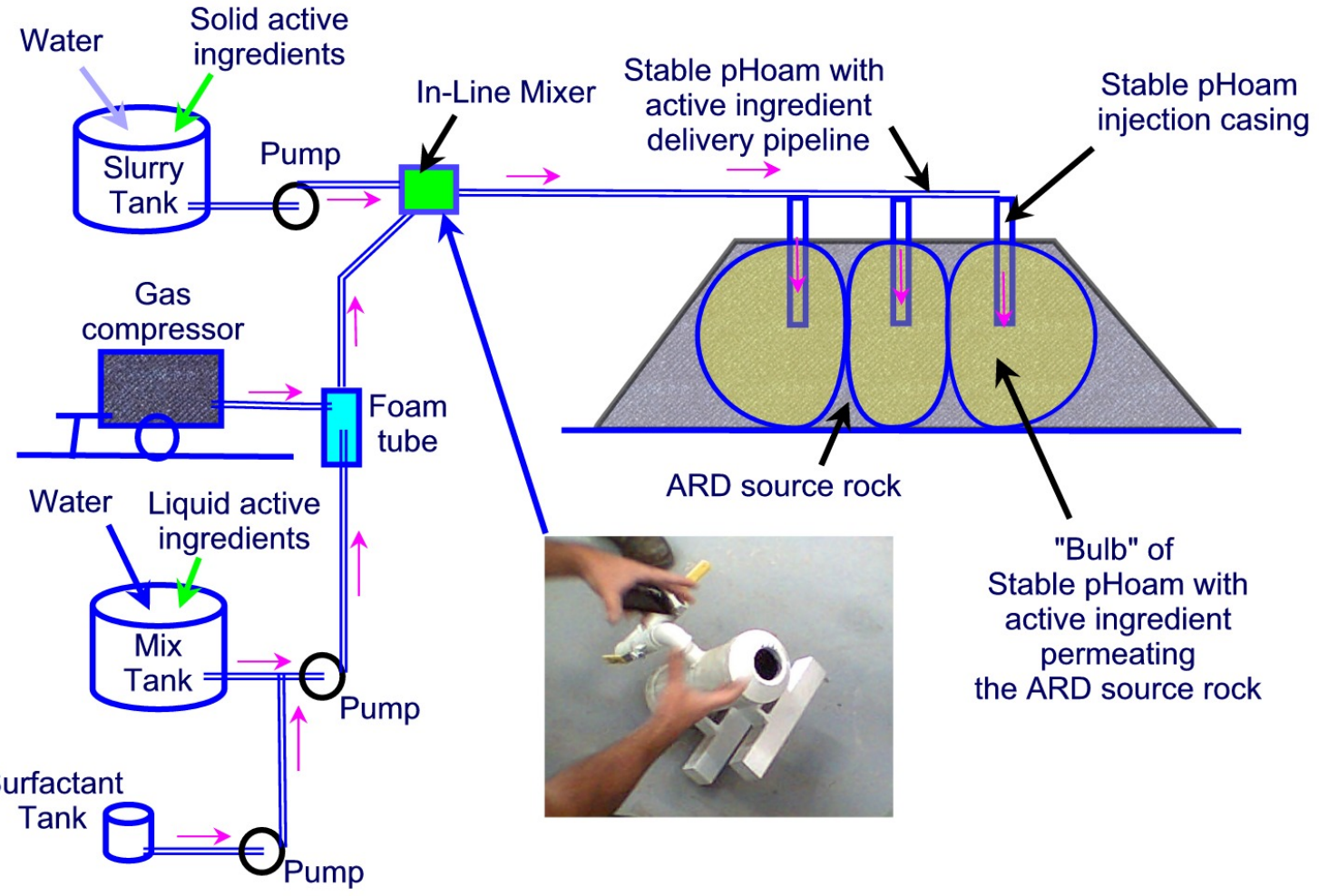

*Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.*

After G.W. Wilson, 2008

# The “Heat-Seeking Missile” Effect in ARD Suppression

- Pyrite oxidation is exothermic
- If a pHoam™ encounters a “hot zone” with elevated pyrite, the bubbles should collapse and preferentially deposit the “active ingredients”
- This feature could potentially give pHoam™ a “***heat-seeking missile***” capability that could automatically deliver more ARD-suppressing active ingredients to a mine waste site in the zones where it is needed the most.

# Implementation Concepts




pHoam injection system layout is simple

# Teaming Partners

- Golder Associates Inc.
  - Water Treatment and Geochemistry Groups
  - Colorado School of Mines Chemistry Dept.
  - Golder Construction Division
- Cellular Concrete Solutions LLC (CCS)
- Site owner/operator or interested entities like watershed groups

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# Development Steps

- Initial patent filing (16 August 2011)
- Initial demo – injecting into a gravel-filled pipe (done)
- Lab Testing (4Q 2011 to 2Q 2012)
  - Entity provides pyrite waste rock dump samples (done)
  - CCS treats samples with foam & amendments (done)
  - Golder/CCS conducts humidity cell tests in-house (ongoing)
  - CCS evaluates foam flow through porous medium (gravel) [planned]

- Demonstration Site (injecting into a real dump) 3Q 2012
- Monitor demo site Q4 2012 and beyond

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# What about CO$T$????

- Need to do comparison with perpetual ARD treatment (either active or passive technologies) or other remedies
- We have a cost model but it has **not** been validated/ calibrated, **so we need demonstration sites**
- Example: to perpetually treat ARD from a 73 hectare waste rock dump in Western USA would cost about $US 30 million. If one assumes that only 25% of the total dump volume would accept or require pHoam™, the treatment cost is on the order of $US 15 million.
- Longevity of the treatment is a big issue. The non-pHoam™ treatment at the Fisher Coal Mine in 1995 with NaOH and bactericide is still effective after 16 years.

# What about CO$T$????

- Our cost model is appears to be most sensitive to the cost of solid active ingredients and the surfactant.
- Even a minor credit for disposal of a local waste (e.g., biosolids) could result in a break-even condition.
- Without the credit, cost of treatment might be less than $1.00 per ton of rock to a fraction of that, depending on whether the rock is “vaccinated” or “medicated”.

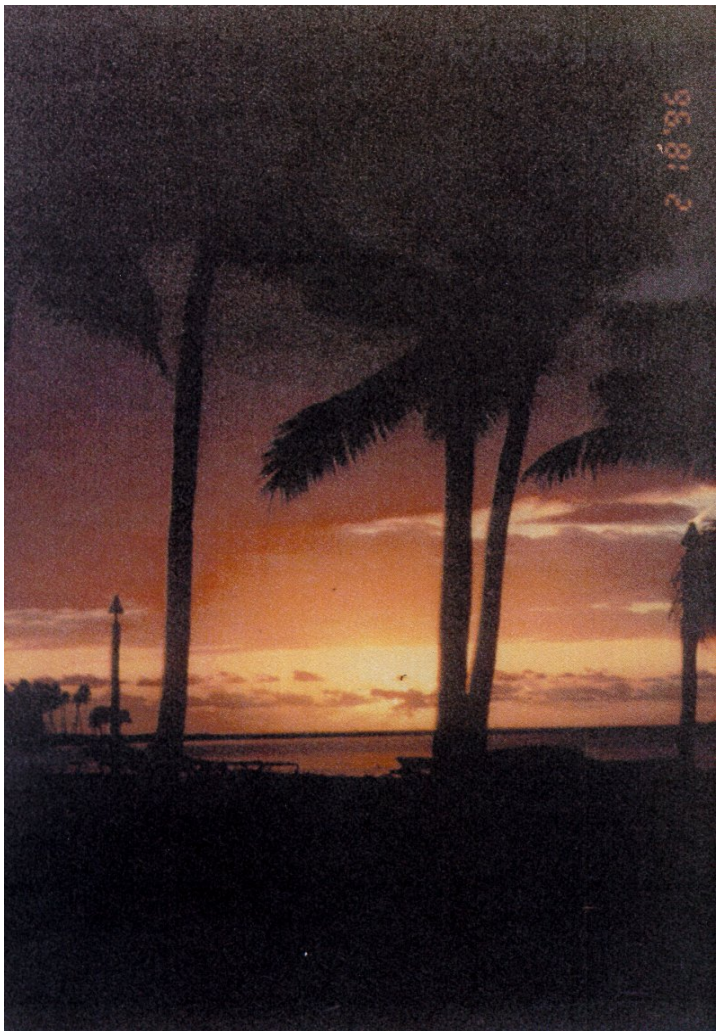
# Ideal pHoam™ Demonstration Site

- Has re$earch funding available
- Contains mine waste that is fully characterized, mapped, and is acid-generating
- Is relatively small in scale (1 to 2 acres) (<1Ha)
- Is relatively accessible by conventional construction equipment
- Is amenable to “dissection” after pHoam application
- Has documented ARD impact
- Is on publicly-owned land (USFS, USBLM, USEPA Superfund)
- Is not a part of or contingent upon ongoing litigation

# WHY IS pHOAM™ SO SPECIAL?

- **Uses very little water**
- Flexible design (wet/dry/stiff/flow-able)
- Flexible longevity (hours to days)
- Flexible active ingredients for suppressing ARD – whatever is inexpensive locally
- Easy to manufacture with traditional equipment
- Heat-seeking missile effect
- Pumpable or flow-able
- Biodegradable surfactants can double as bactericides
- Permeates unsaturated zones of mine waste to deliver anti-ARD “cocktail” that could last for decades, maybe longer

# Thank You



*Nihil simul inventum est et perfectum*

*Latin Proverb*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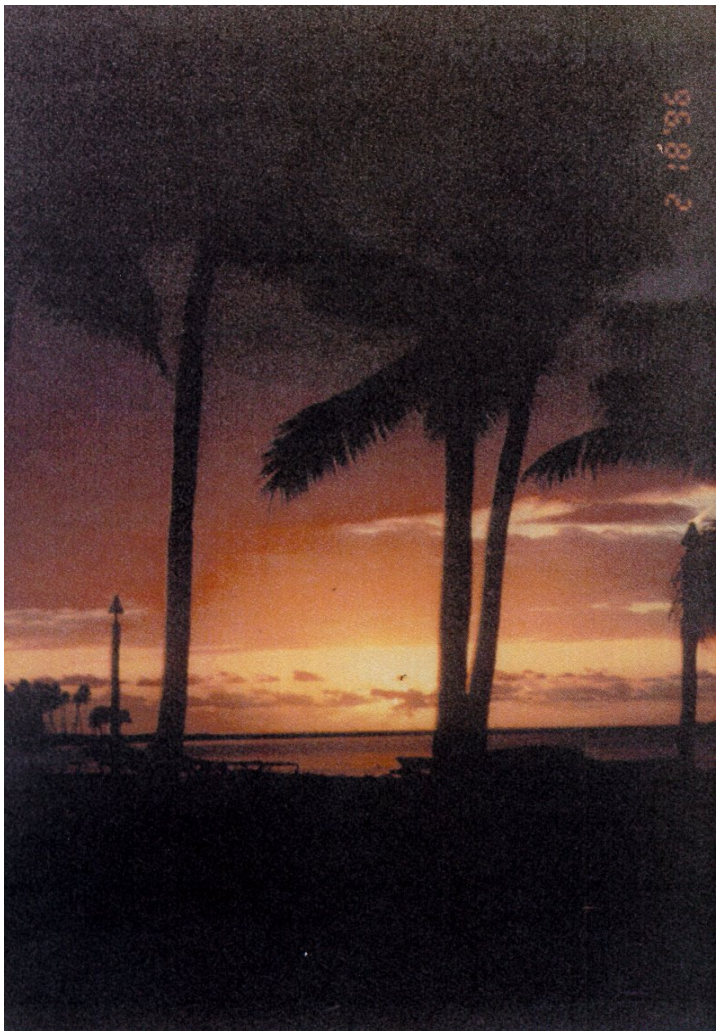
# Thank You



Nothing is invented and perfected at the same time

*Latin Proverb*

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