An Innovative Method for Mitigating Impacts from Acid-Producing Rock

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Acid Rock Drainage

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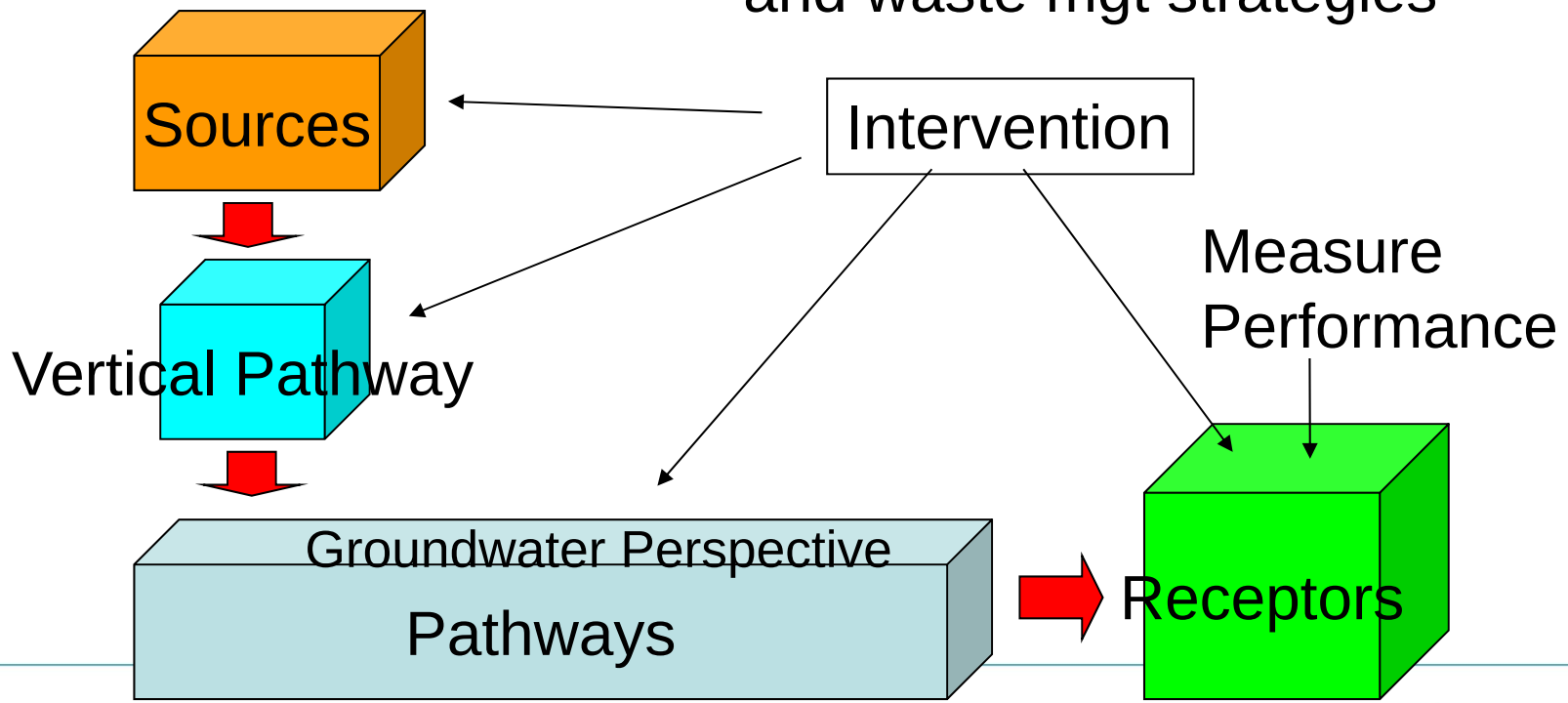
Overview of Best Practice Methods

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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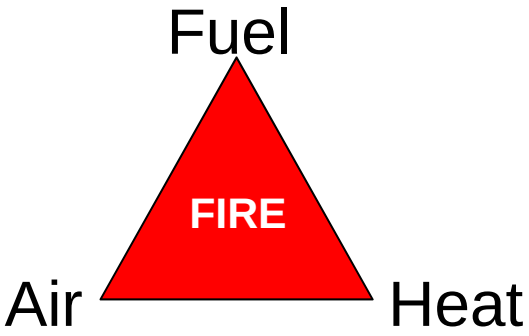
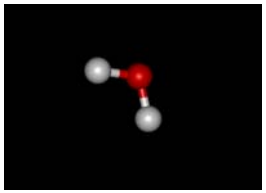
Acid Rock Drainage Tetrahedron

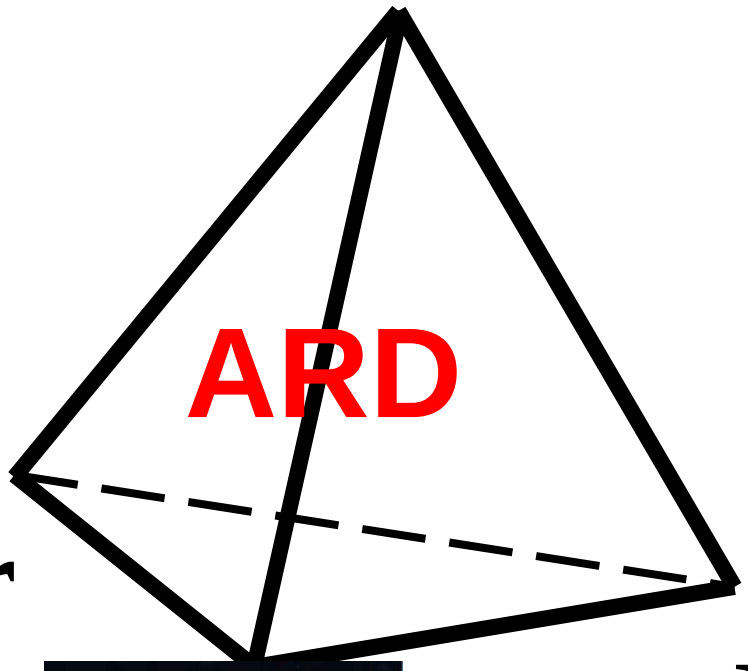


Water



Oxidizer

(Air, Fe^{+3})



Bacteria

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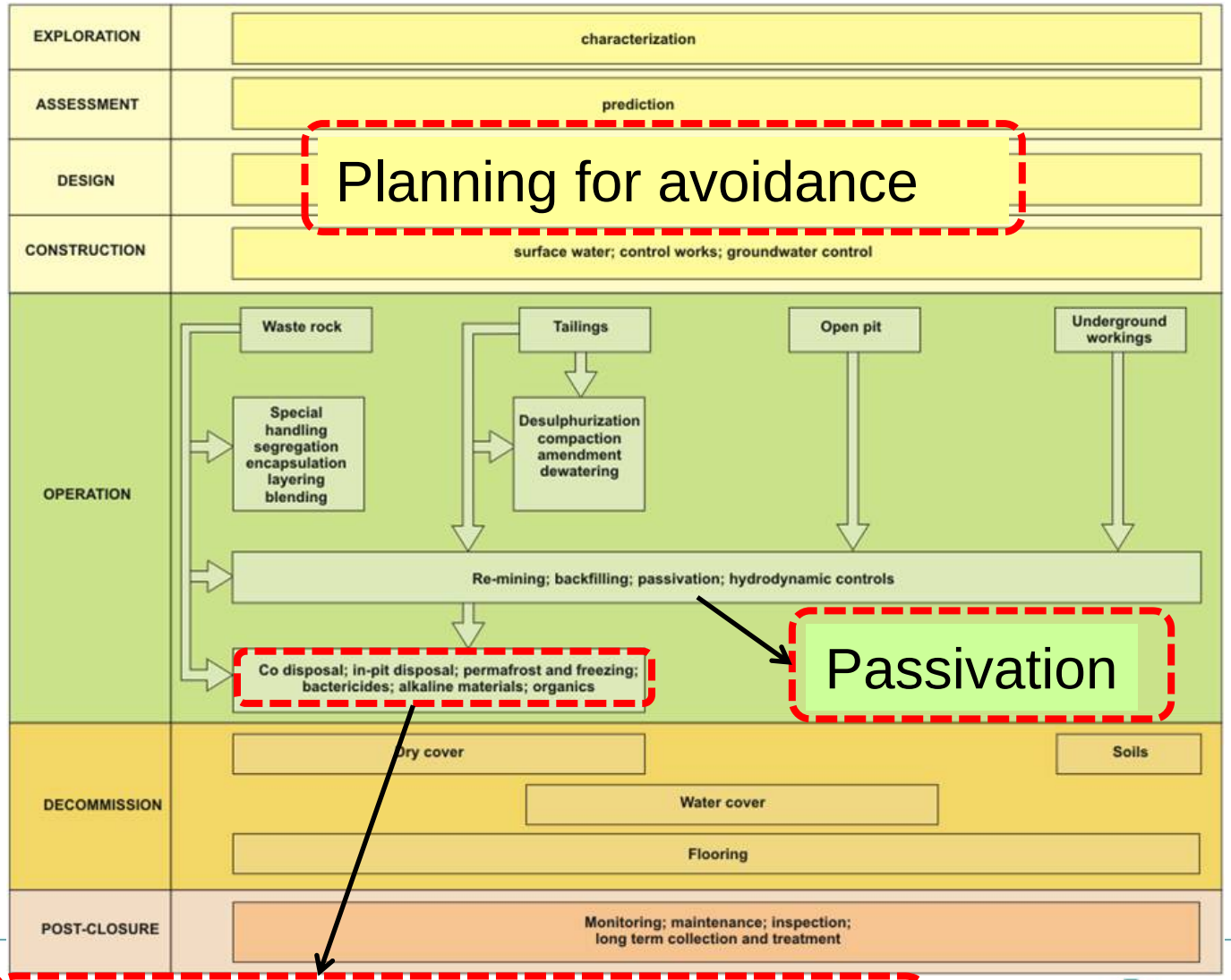
ARD Mitigation Framework

REF:
GARD Guide 2010

Also see:

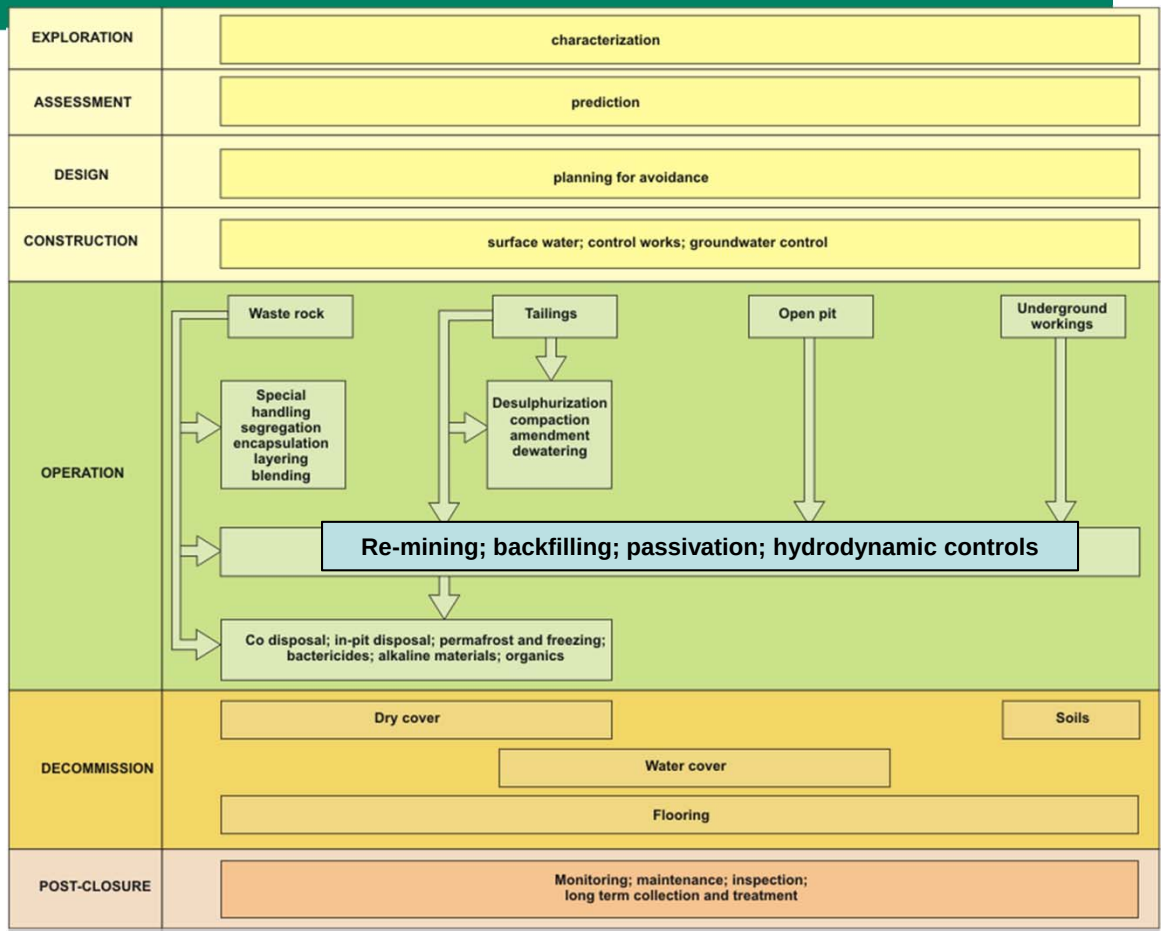
Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania; Brady et al., 1998



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

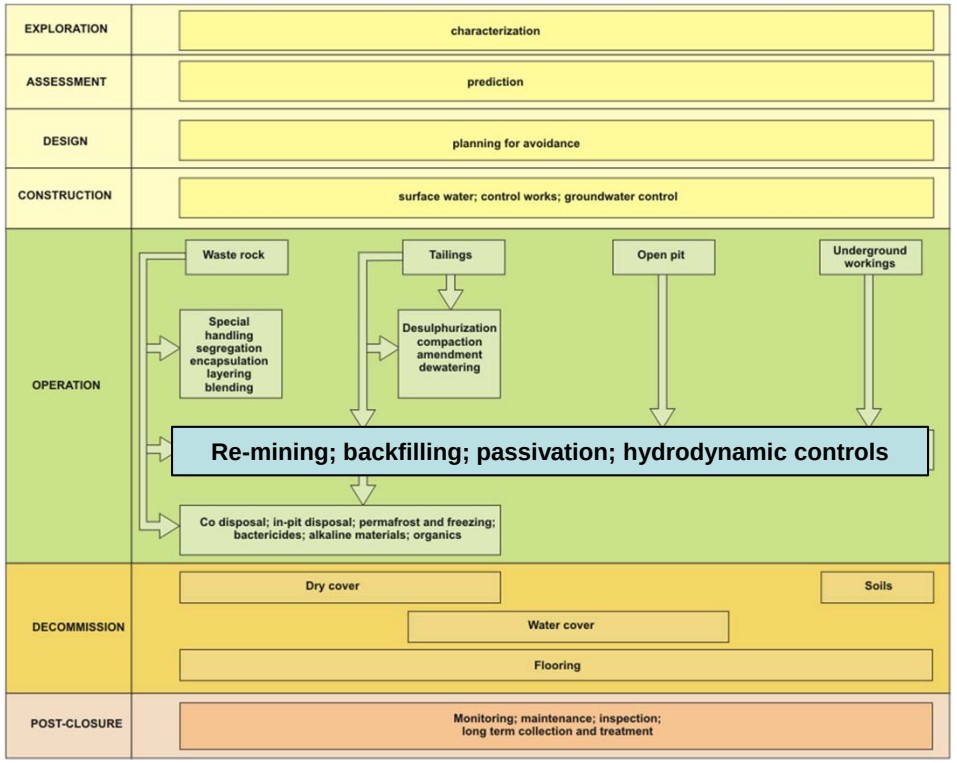


What about *abandoned* mines?

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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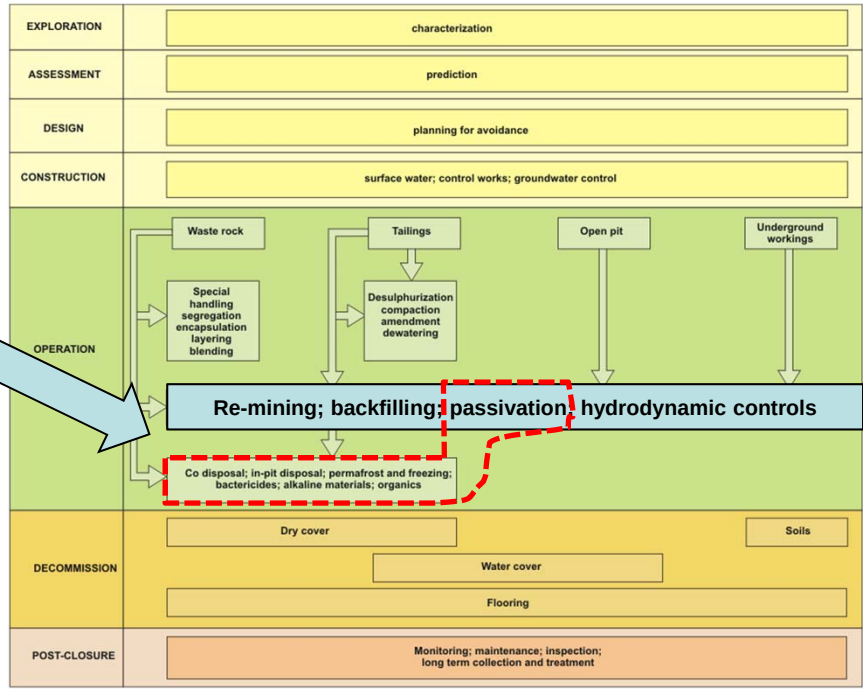
Best Practice Methods- Passivation

- 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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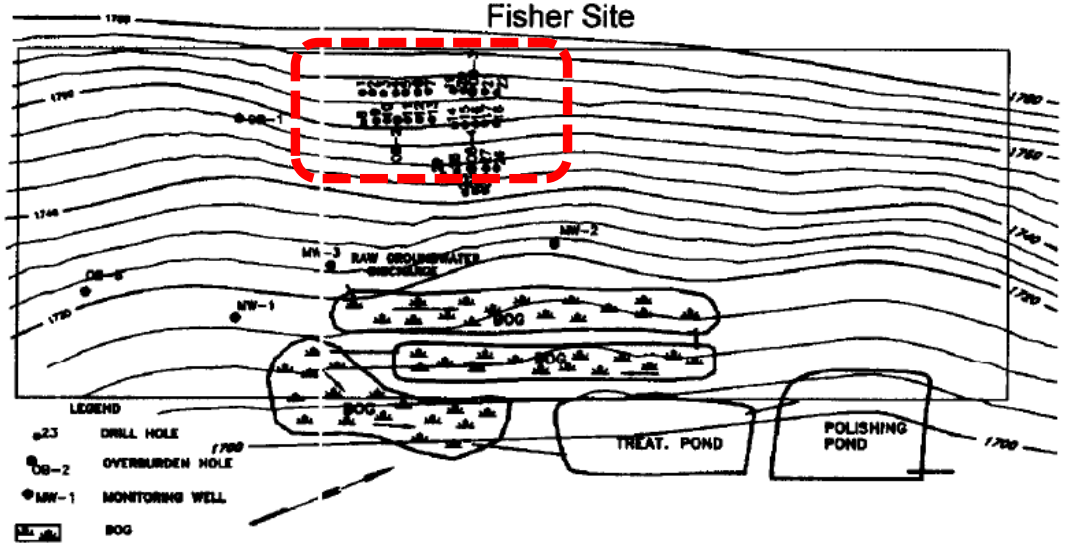
Has it been done before?

- **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

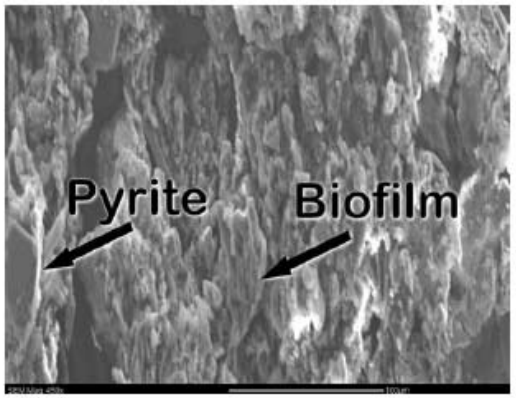


Fig. 6 Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (*ES*) and 5× the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing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

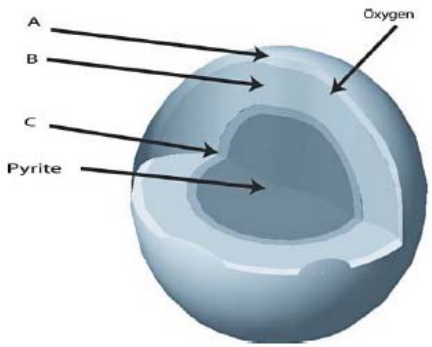


Fig. 7 Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of aerobic and facultatively anaerobic bacteria that consume oxygen (O_2) diffusing through the biofilm from overlying water. Layer C is an anaerobe-dominant layer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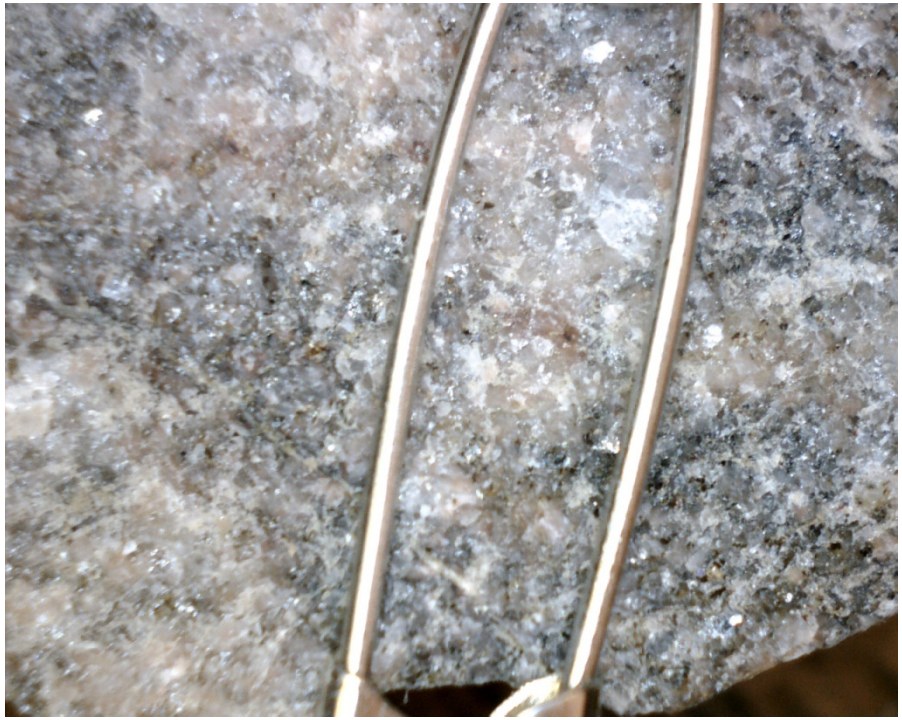
Recent Experiments in the Laboratory



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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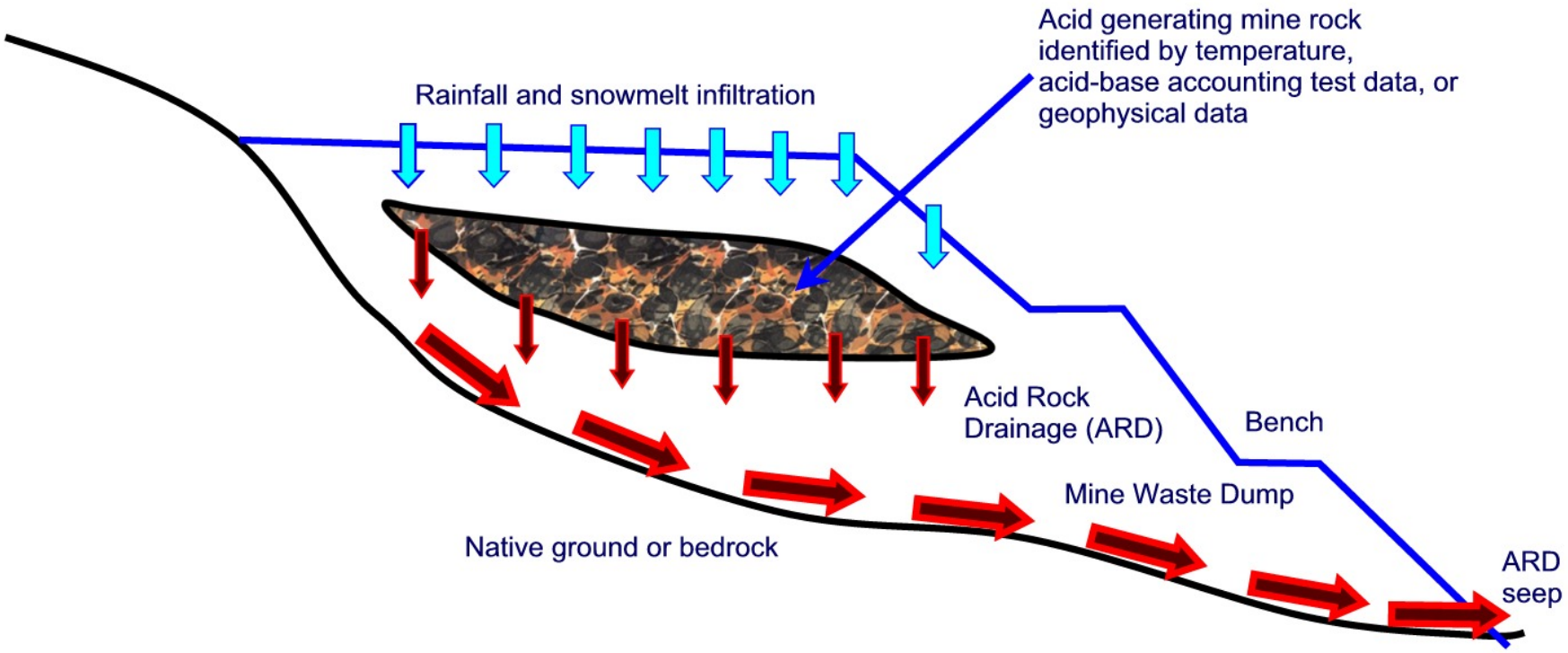
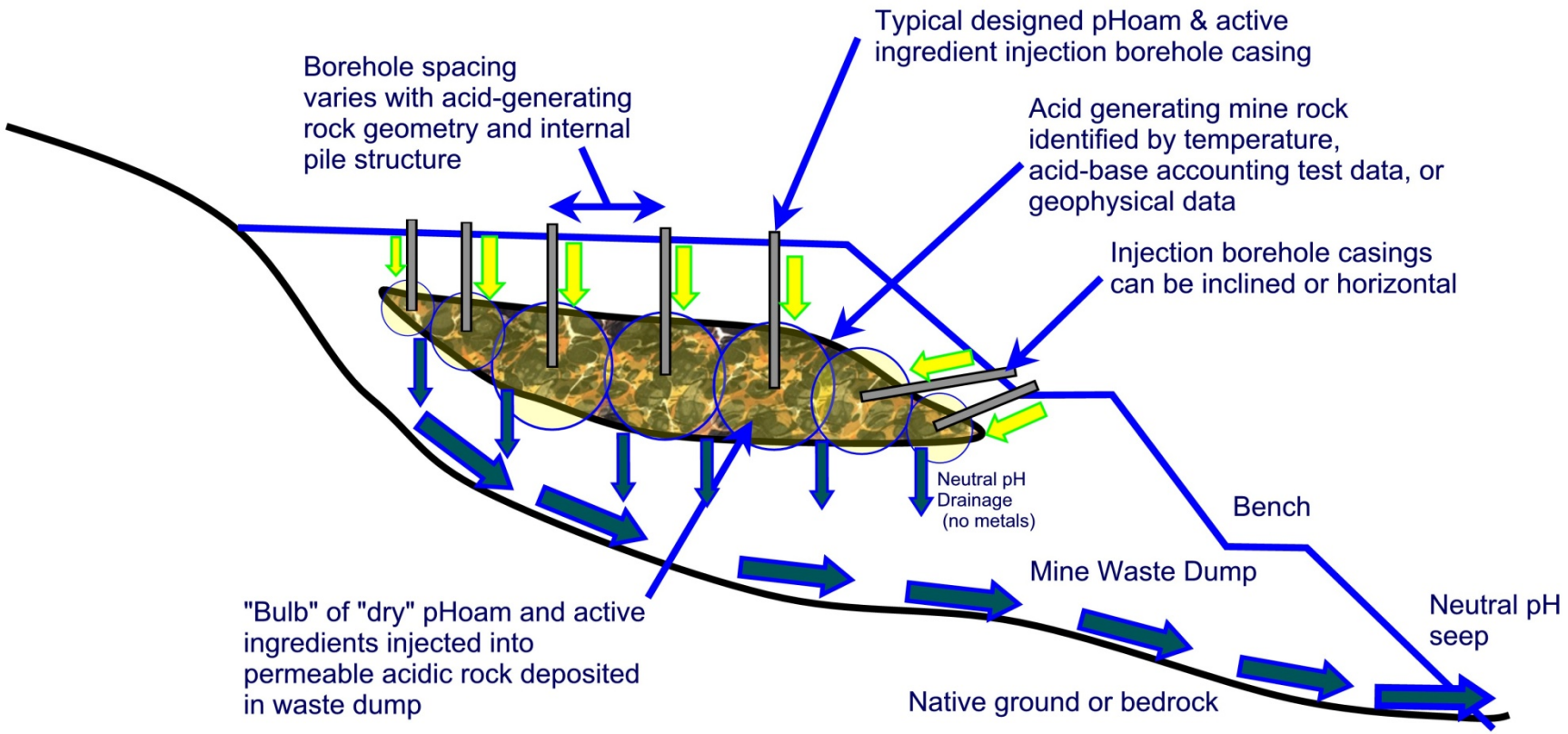
Application Concept: Mine Dumps



Waste Rock Dump = Big Humidity Cell

Application Concept: Mine Dumps



Waste Rock Dump

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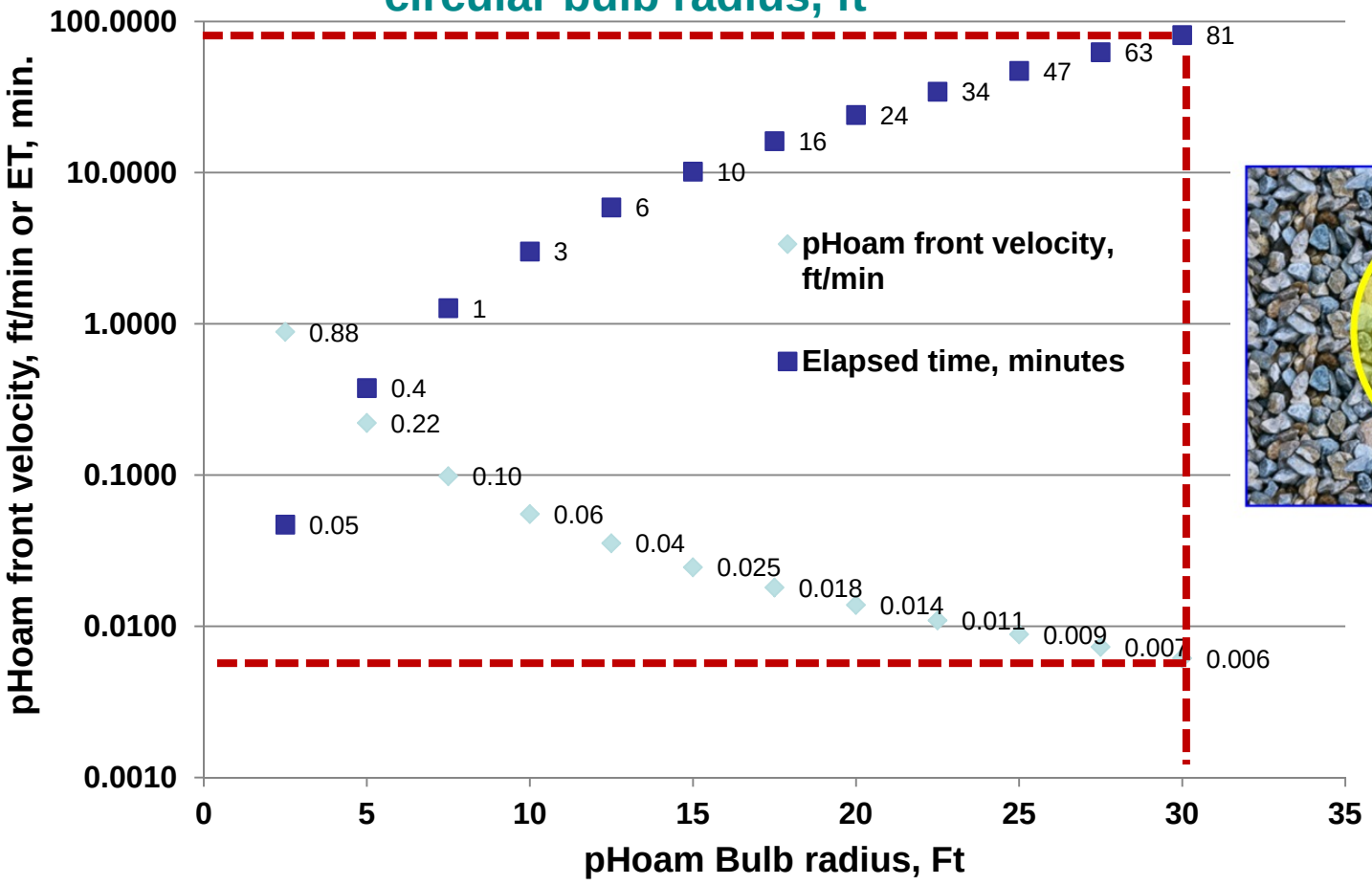
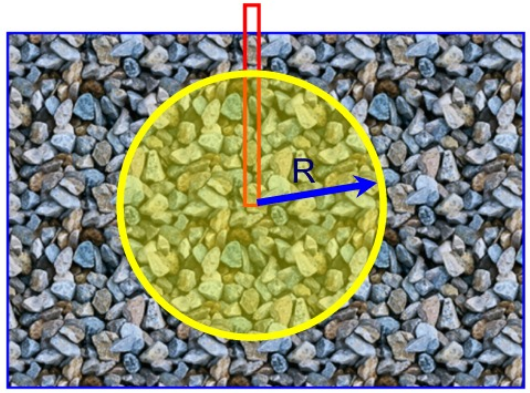
pHoam injection kinetics - theory

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

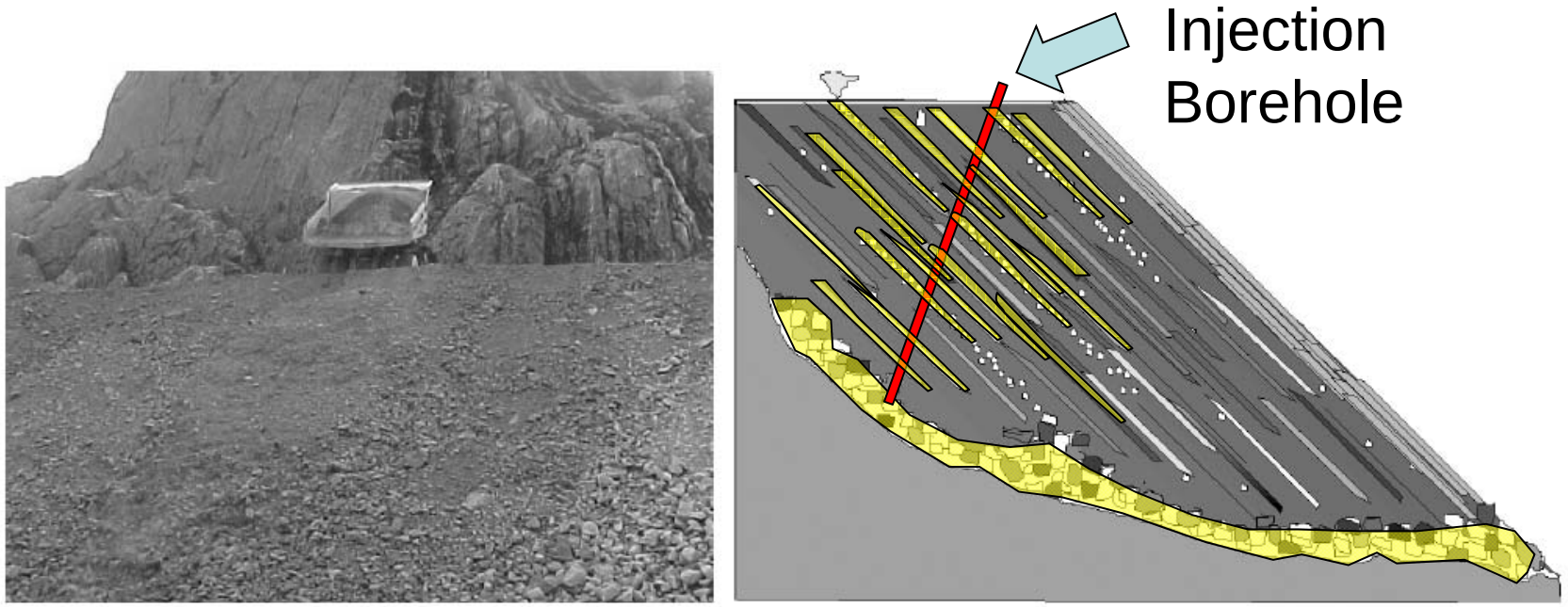


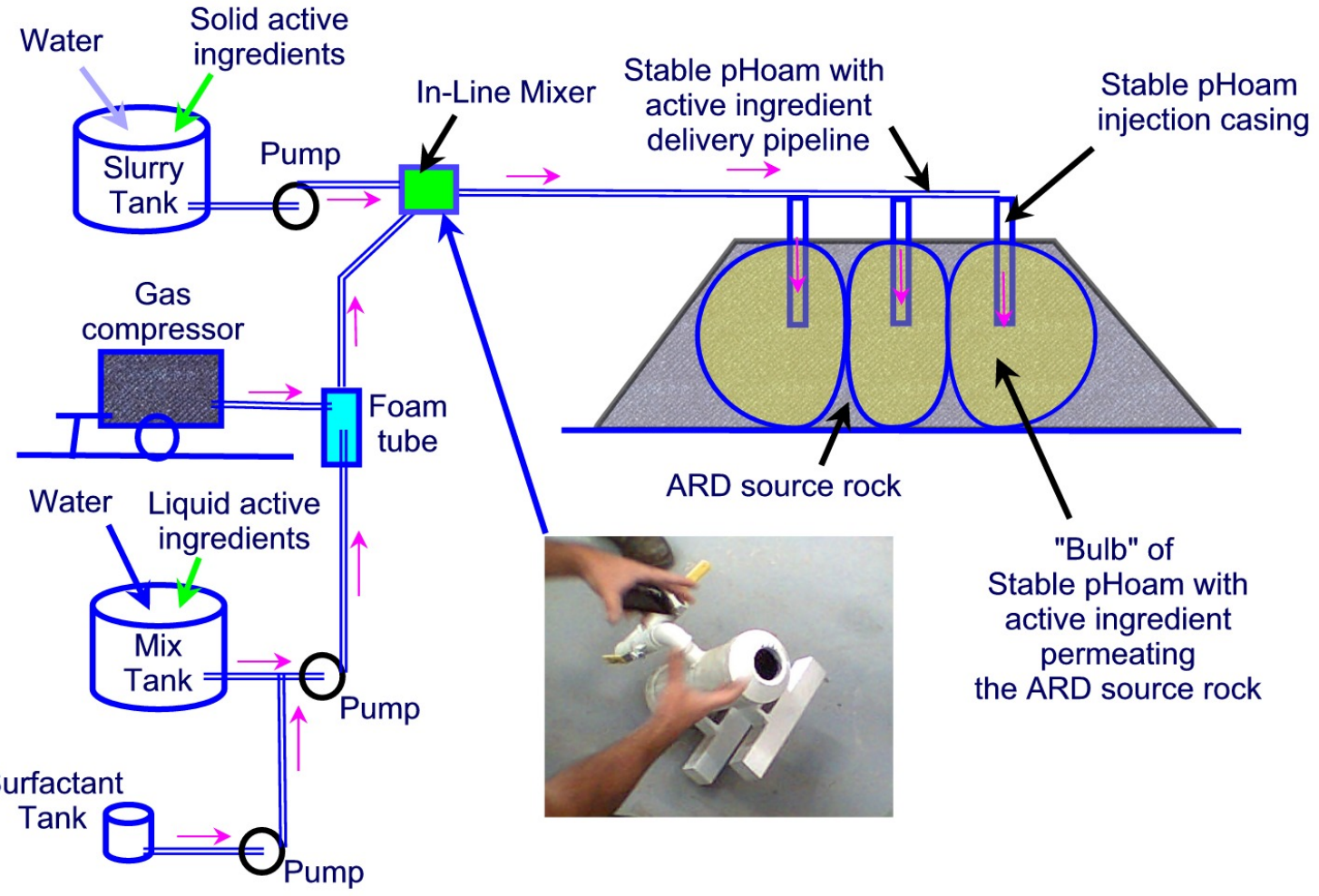
Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

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 COT????

- 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 COT????

- 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”.

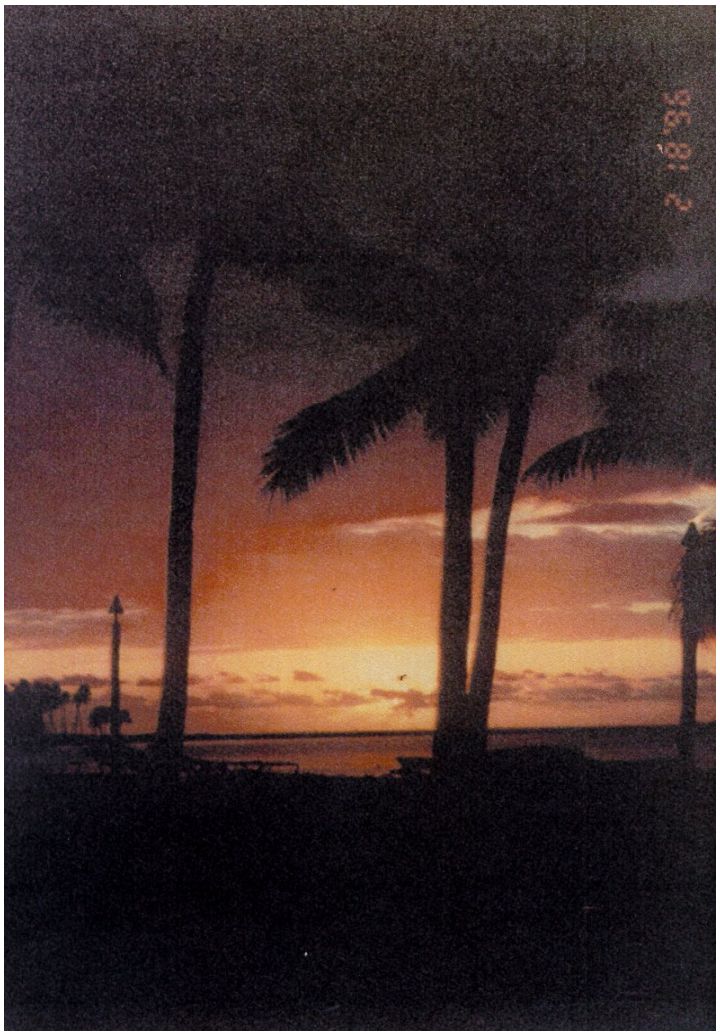
Ideal pHoam™ Demonstration Site

- 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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or

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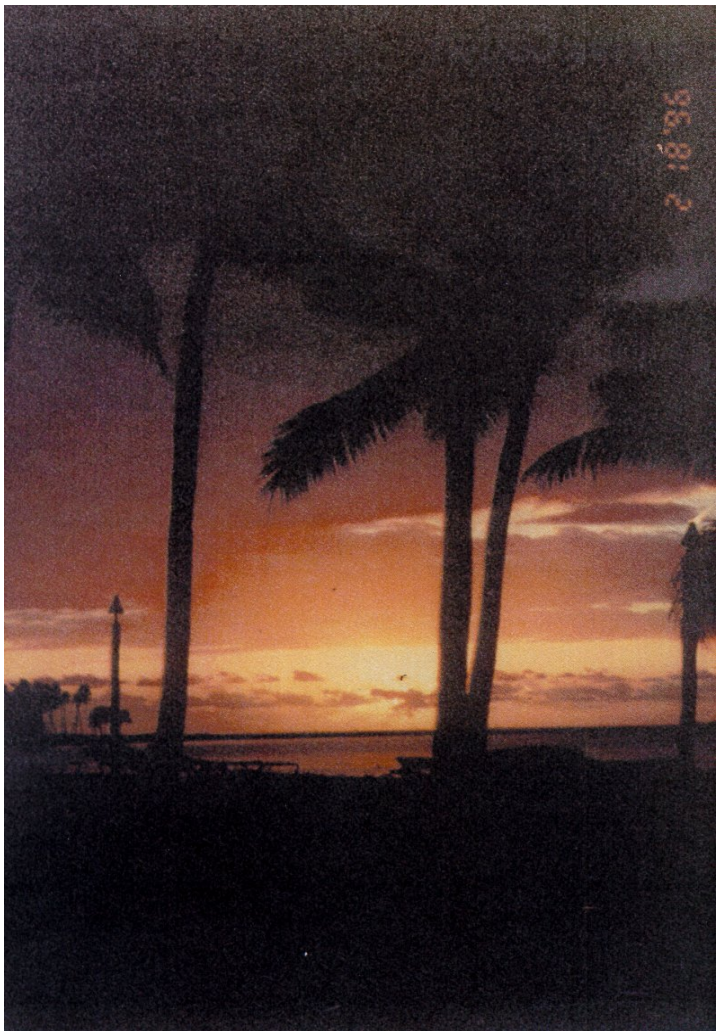
Thank You



Nothing is invented and perfected at the same time

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