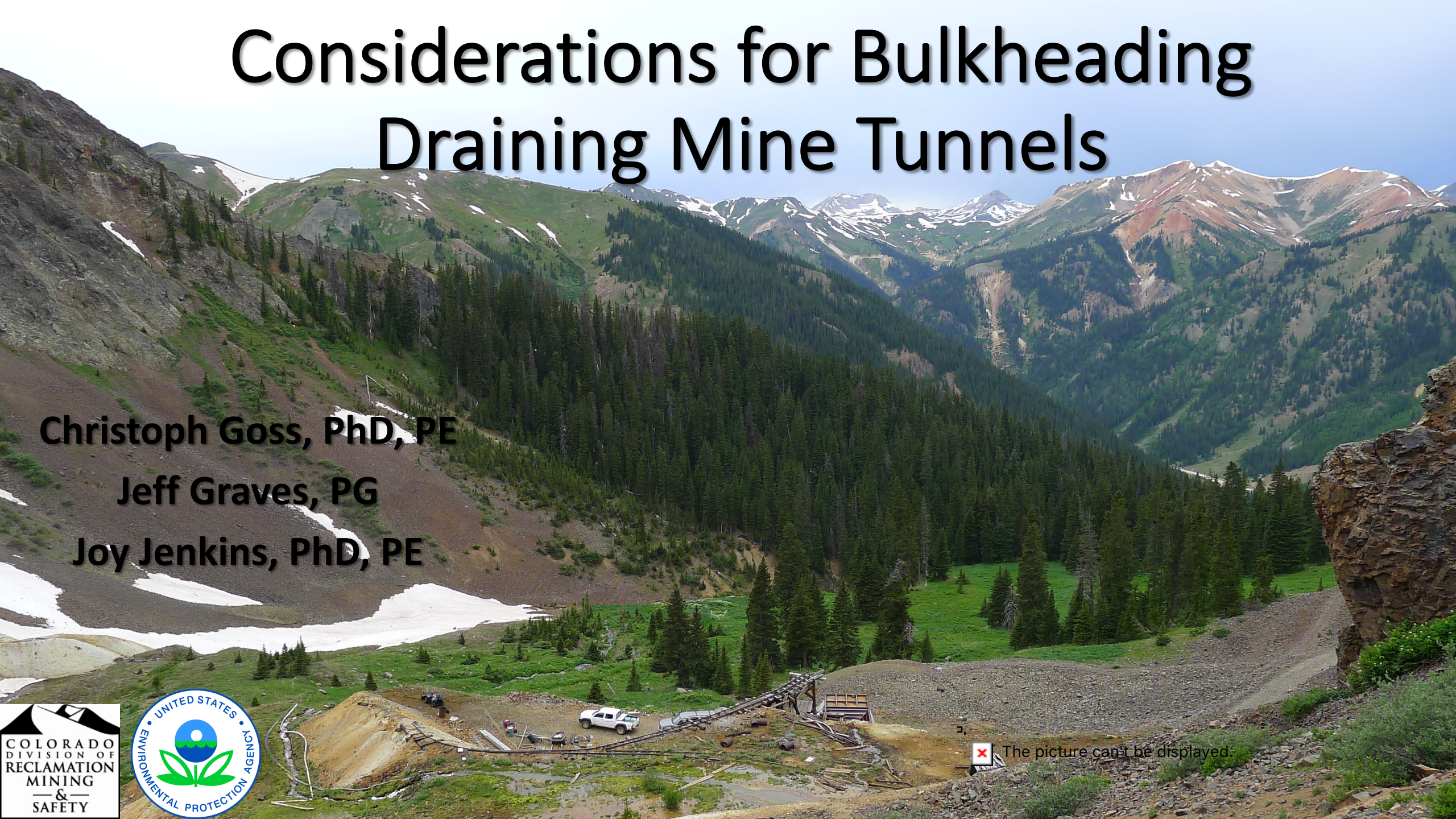
Considerations for Bulkheading Draining Mine Tunnels

Christoph Goss, PhD, PE

Jeff Graves, PG

Joy Jenkins, PhD, PE

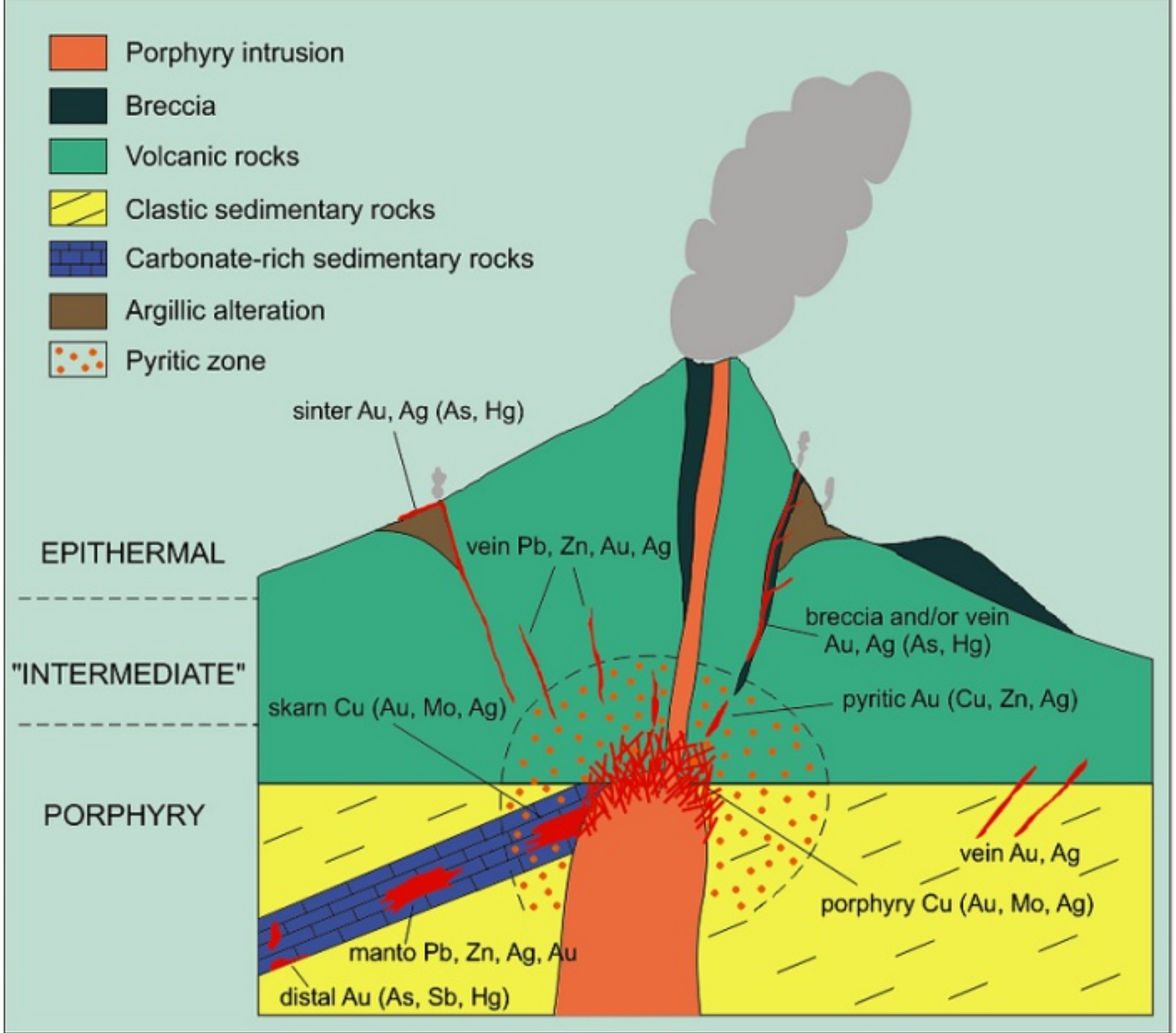


The picture can't be displayed.

Outline

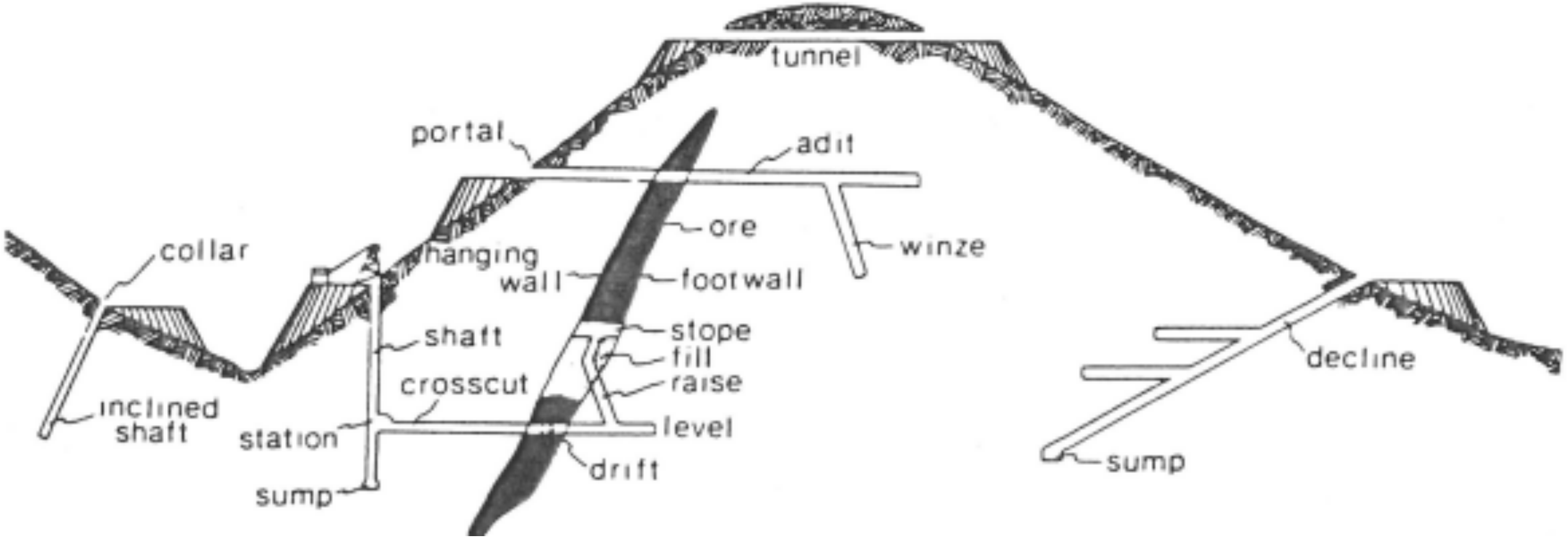
- Hard rock mine cycle overview
- What is a bulkhead?
- Bulkhead design
- Bulkhead risks
- Integrating a bulkhead into the site plan
- Post Bulkhead Installation (care and feeding of your bulkhead)

Typical Source of Metal Mineralization



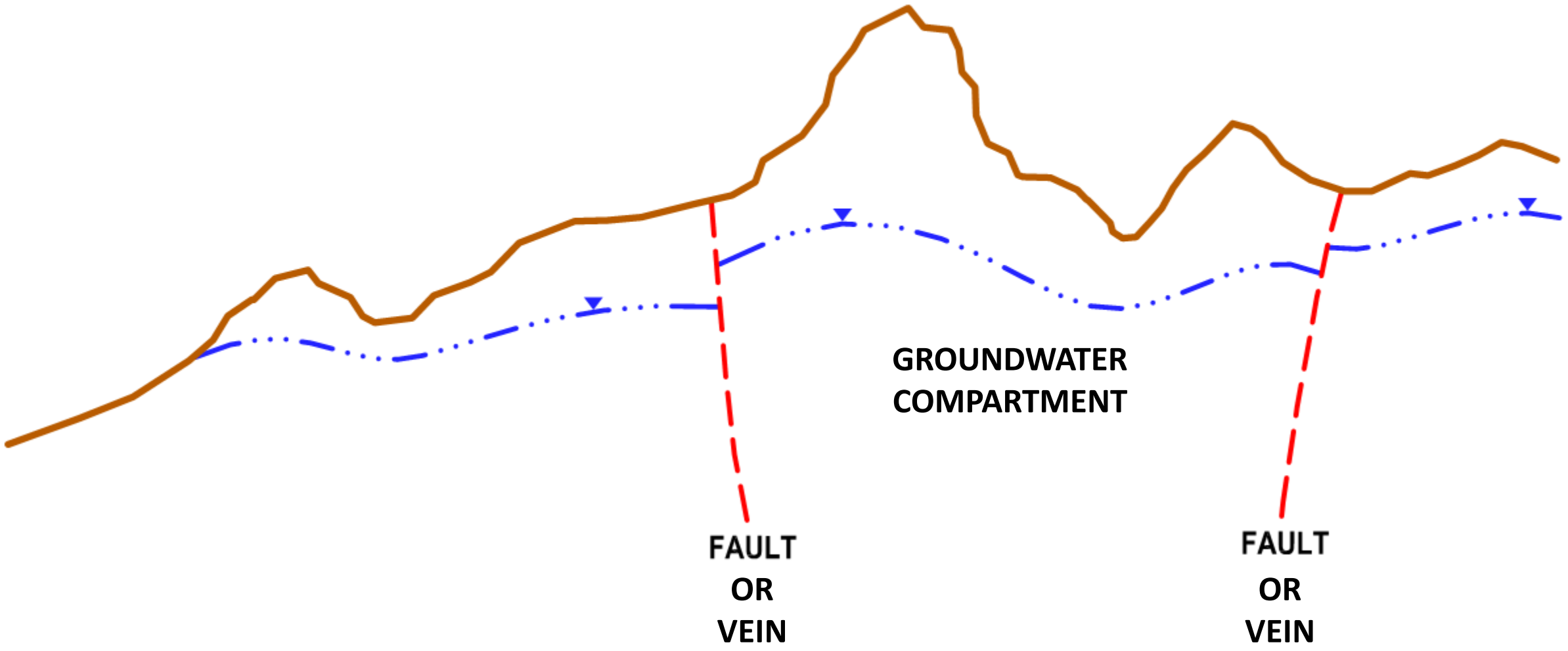
Kirkham and Sinclair, 1995

Underground Mining Terminology

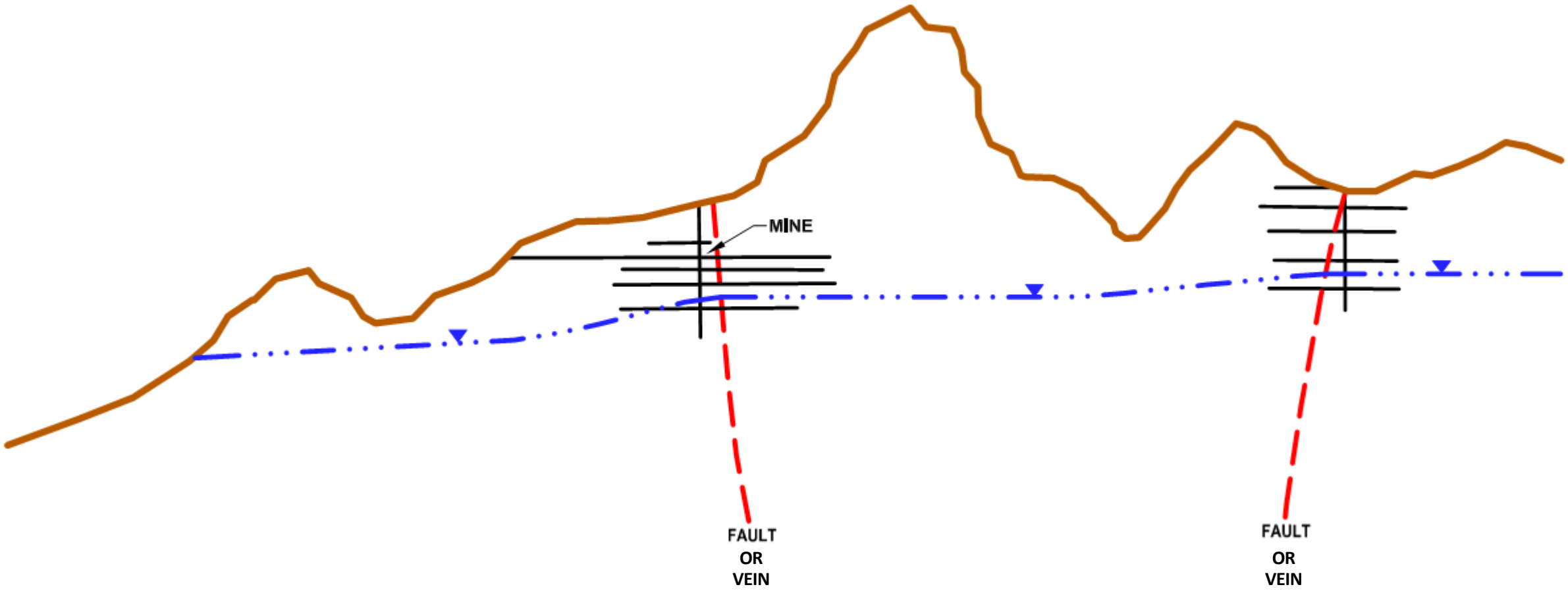


Mining Engineering Handbook p29, 1992

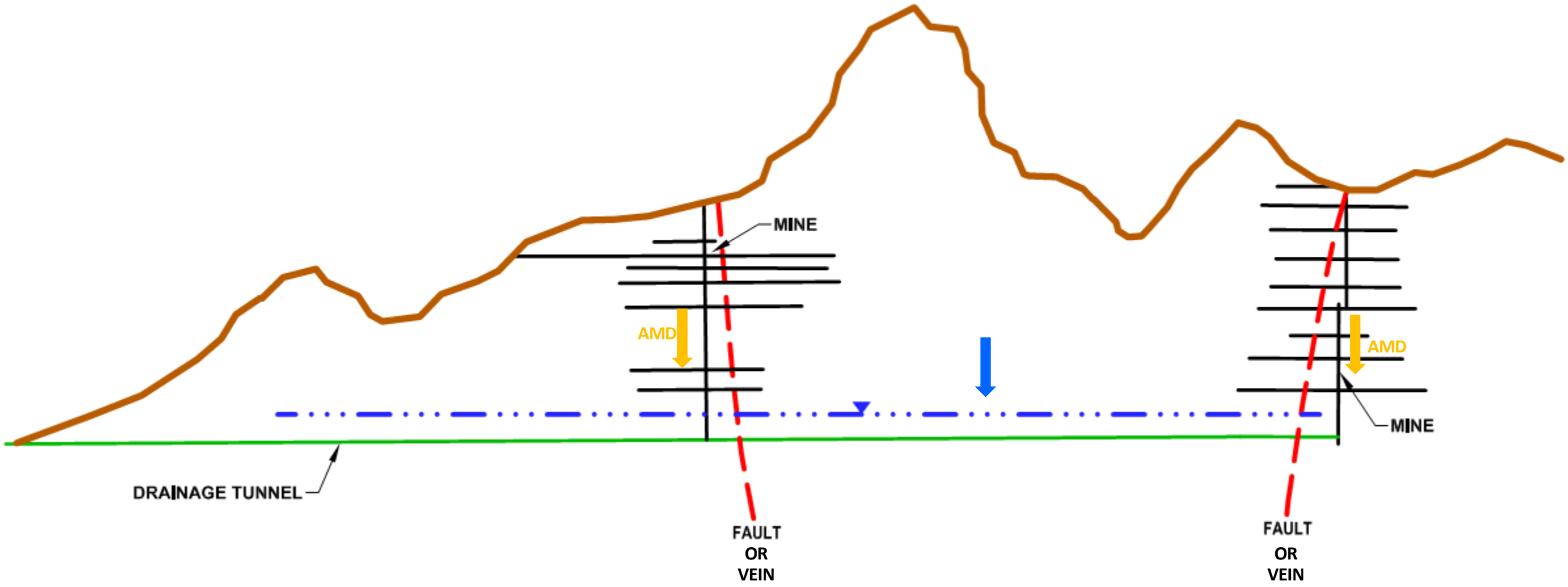
Pre-Mining Cross Section



Early Phases of Mining Cross Section



Late Phases of Mining Cross Section



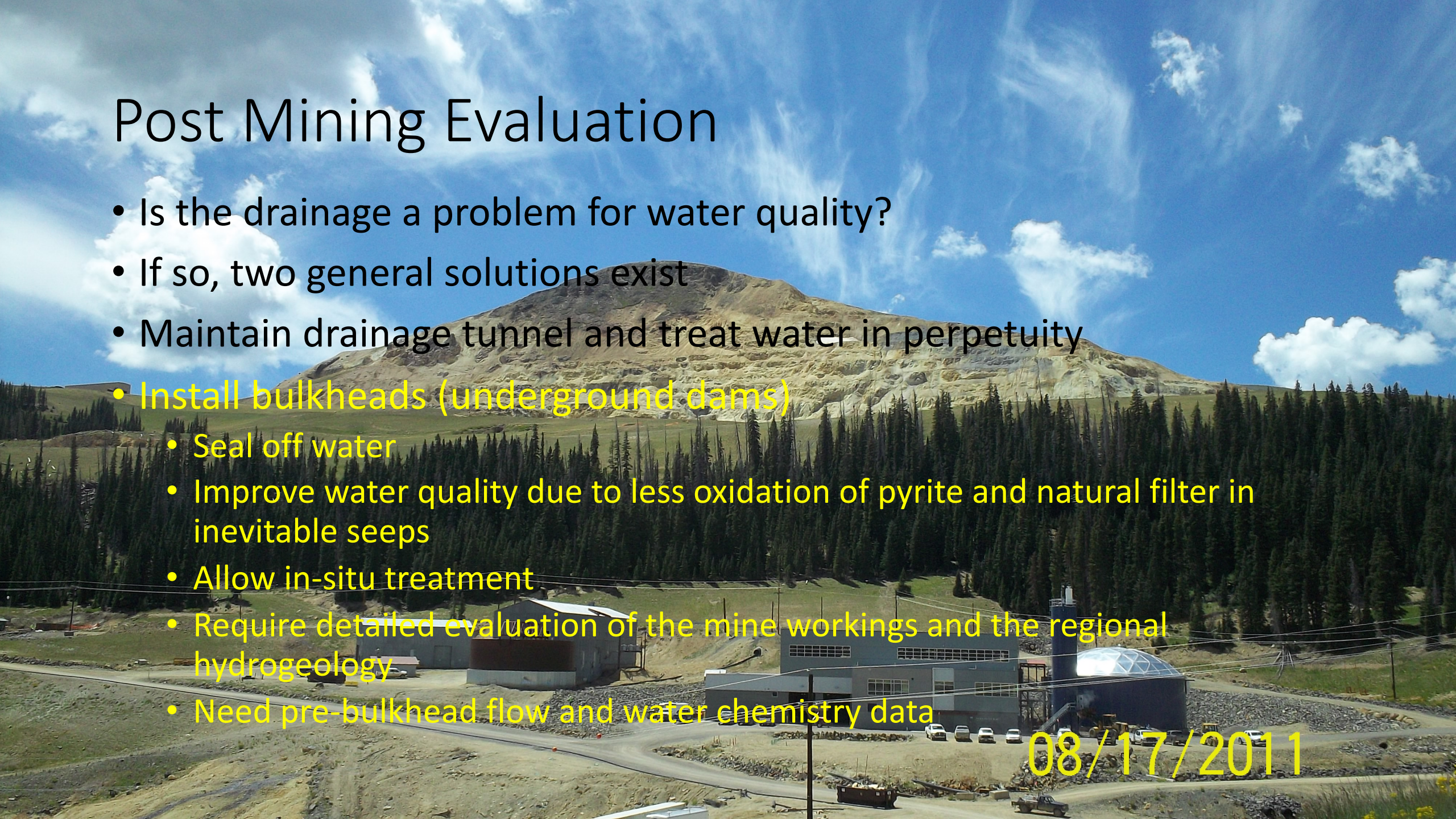
End of Mining

- Mines abandoned
- Low drainage tunnels continue to drain
- Oxygen in mines reacts with pyrite to form sulfuric acid and dissolve metals: AMD
- Metal precipitate, bacterial ooze, and other material builds up
- Blockages from roof falls create temporary dams that eventually overtop resulting in surges from the portal
- Portal collapses and water flows unchecked through debris

Sludge Behind Portal

Post Mining Evaluation

- Is the drainage a problem for water quality?
- If so, two general solutions exist
- Maintain drainage tunnel and treat water in perpetuity
- Install bulkheads (underground dams)
  - Seal off water
  - Improve water quality due to less oxidation of pyrite and natural filter in inevitable seeps
  - Allow in-situ treatment
  - Require detailed evaluation of the mine workings and the regional hydrogeology
  - Need pre-bulkhead flow and water chemistry data

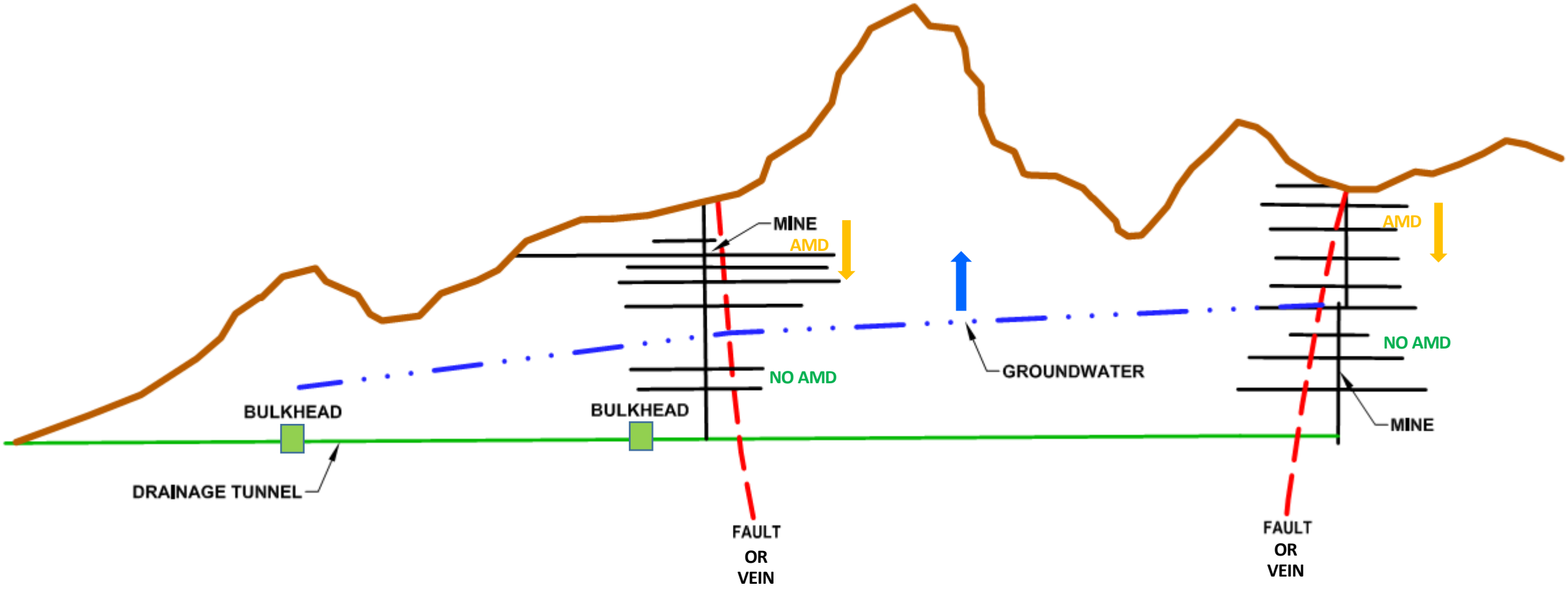


08/17/2011

Post Mining Groundwater Table with Bulkheads

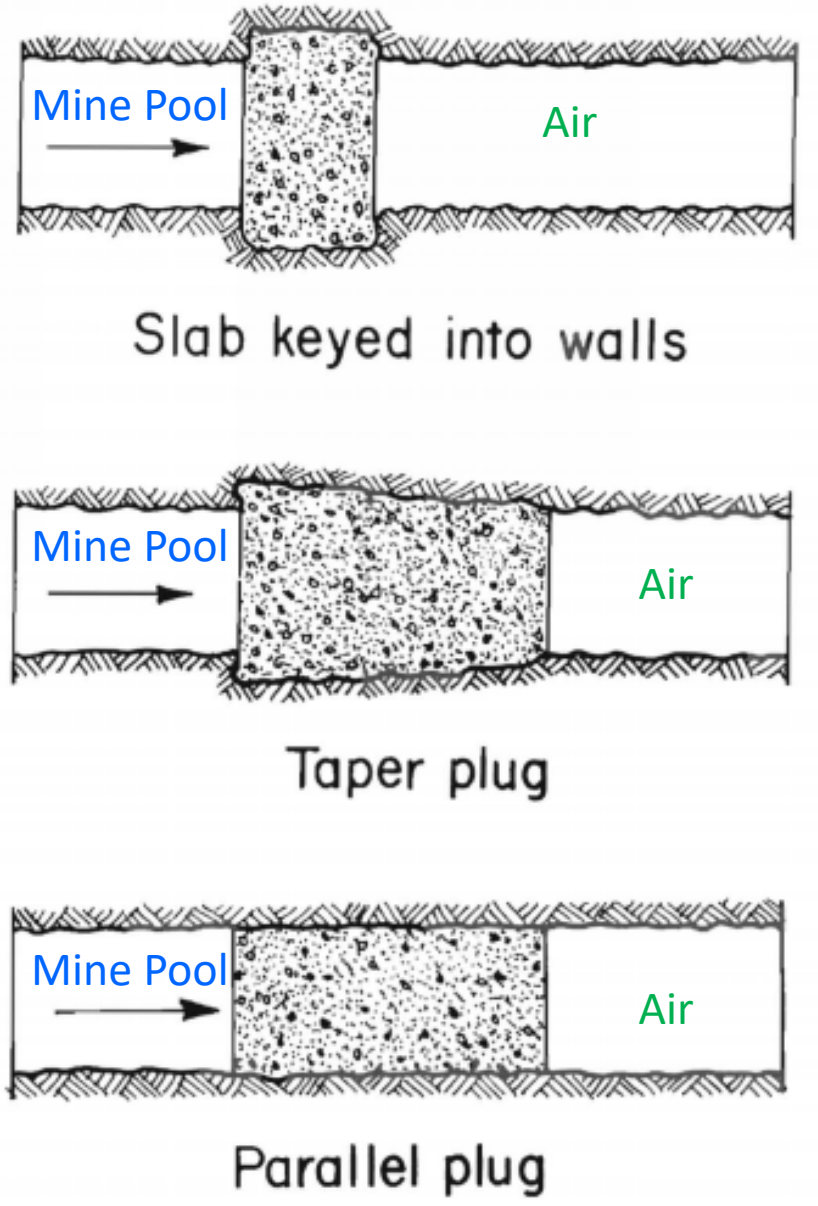
- Key parameter that determines:
  - How many levels will flood
  - Number of bulkheads needed
  - Pressure on bulkheads
  - Locations of likely seeps and springs
  - Impact on other mines (active and inactive)
  - Overall feasibility
- Estimating pre-mining groundwater table is a good starting point
- Evaluate how new enlarged fractures (mine workings) will impact fracture flow system
  - Permeability along faults
  - Permeability across faults (groundwater no longer compartmentalized)

Post-Mining Cross Section with Bulkheads



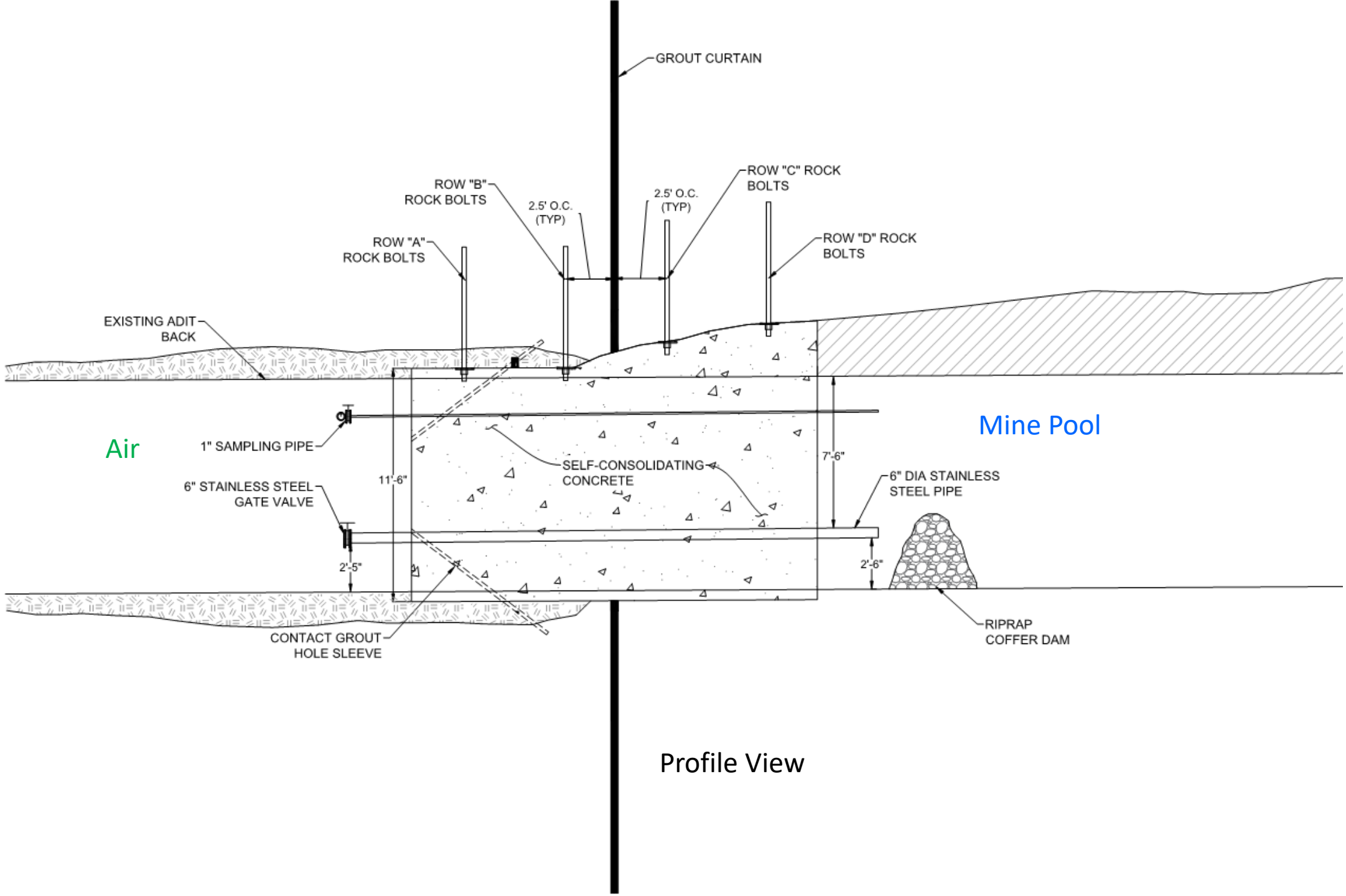
What is a Bulkhead?

- Engineered concrete plug designed to hold back water long term
- Common in mines and hydroelectric tunnels

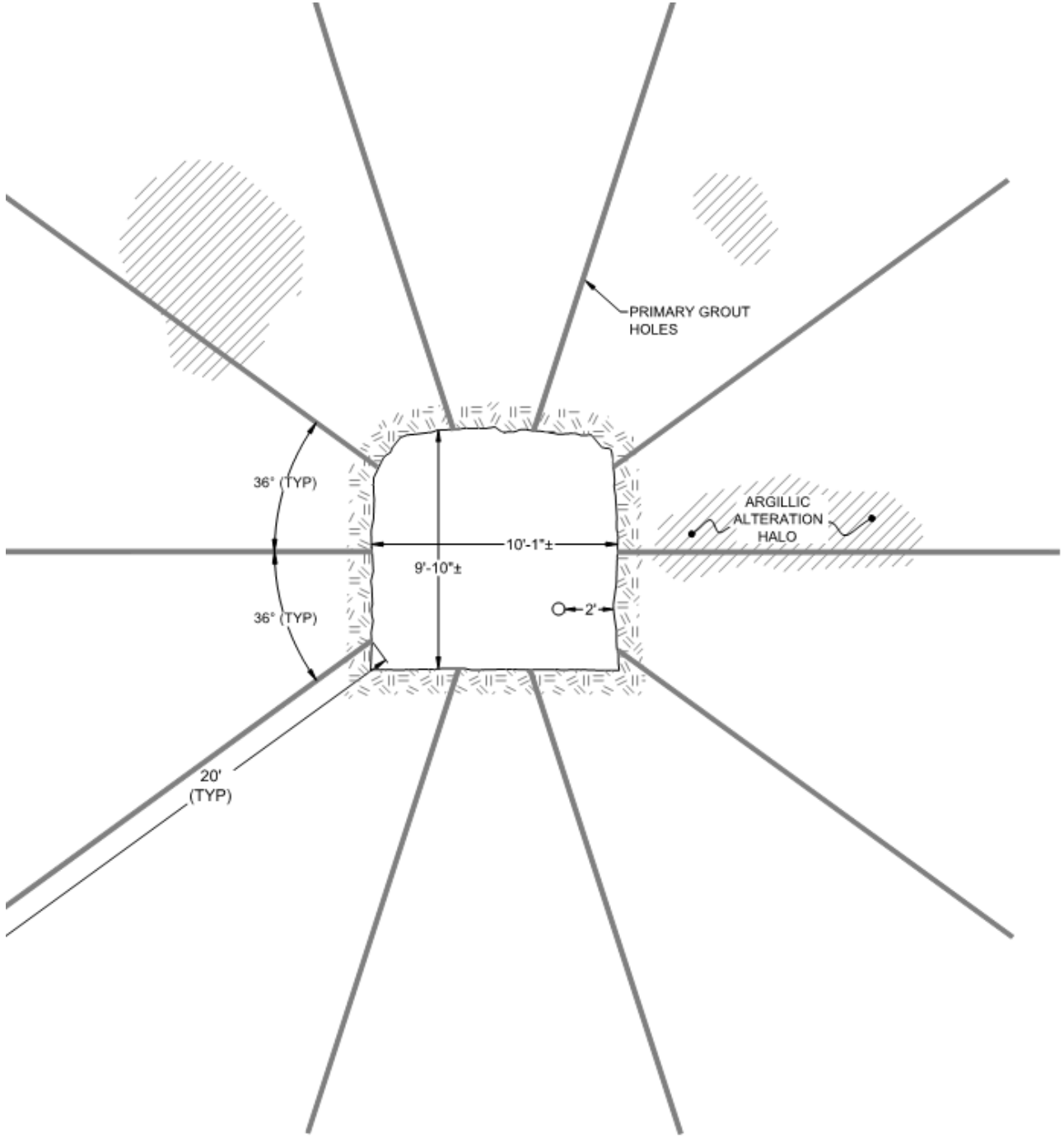


Plan and Profile Views

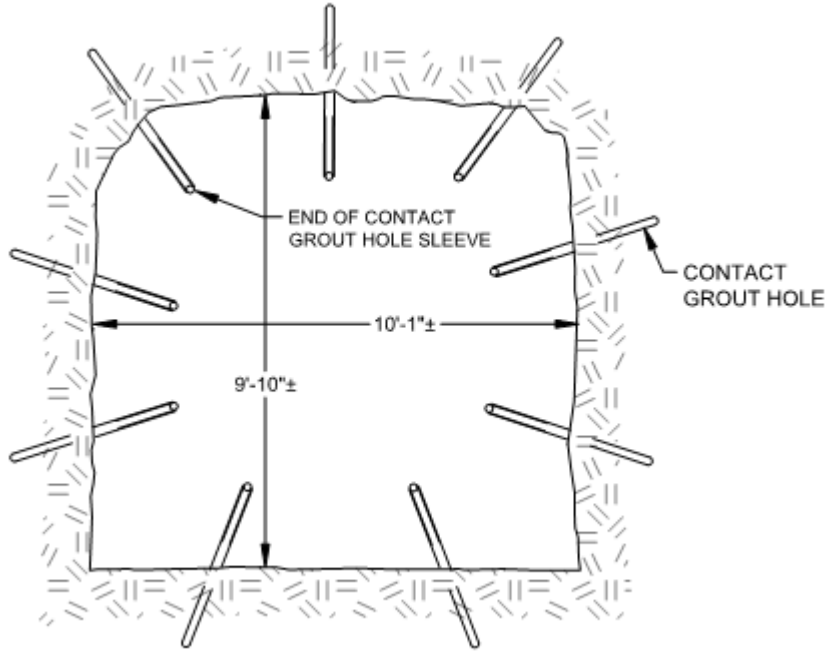
Modified from Chekan 1985

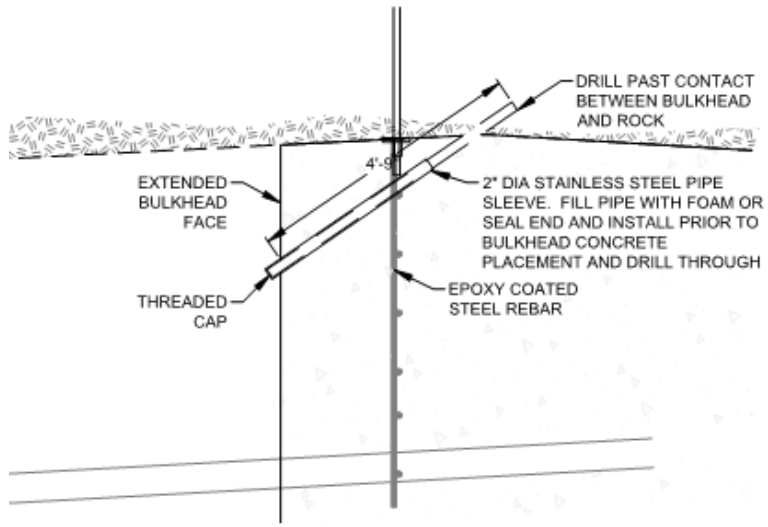


Profile View



TYPICAL GROUT HOLE PATTERN





CONTACT GROUTING PIPE SLEEVE DETAIL


Collapsed Portal…Not a Bulkhead

Collapsed Tunnel

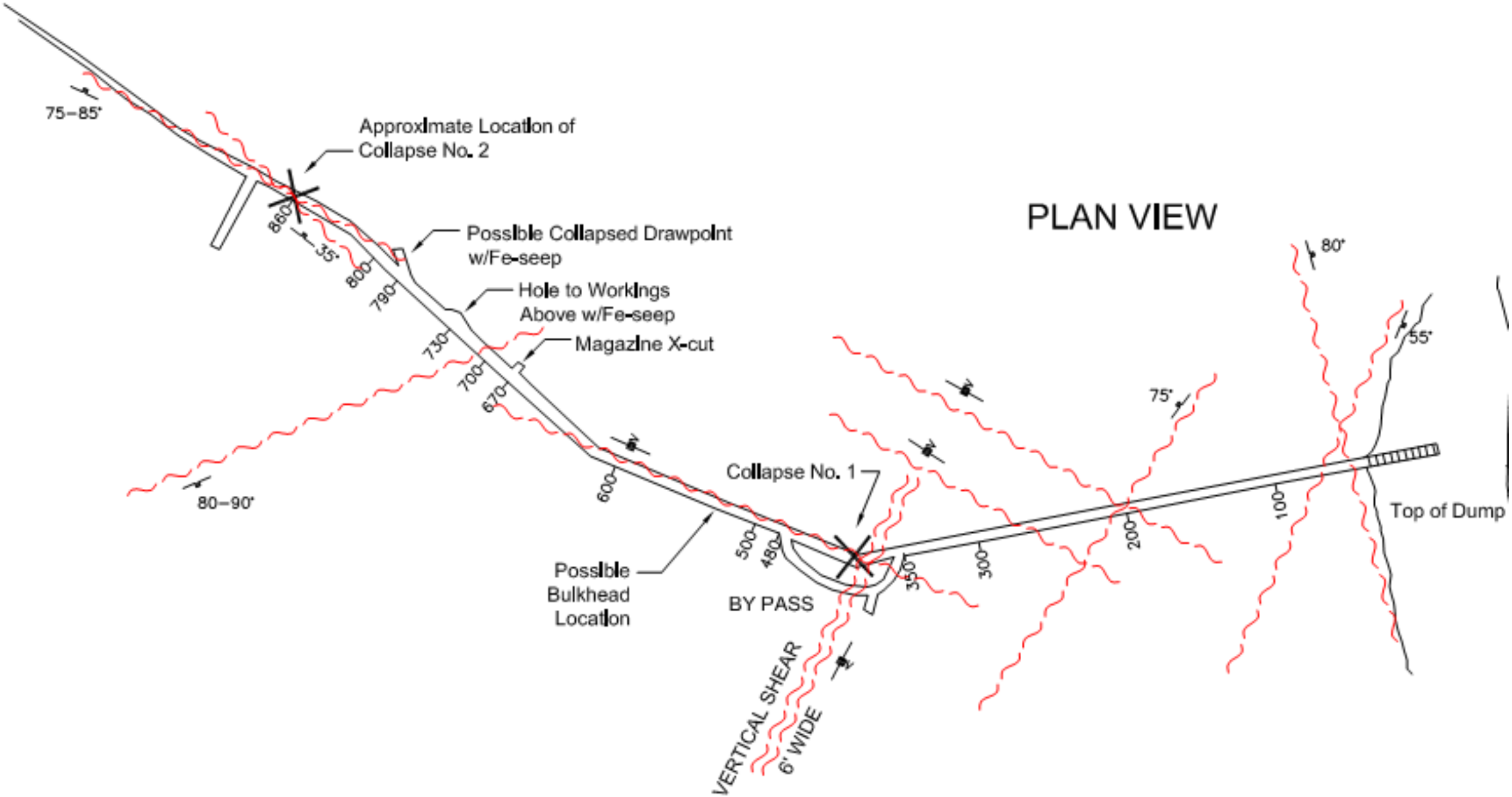
Not a Bulkhead


This is a
bulkhead


This is a
bulkhead

Bulkhead Placement

- Under enough cover (deep in mine)
- In good ground
- In pairs?
- At lowest level and moving up to plug levels that will be inundated
  - Includes other mines in area that are hydrologically connected
    - Workings
    - Veins
    - Drill holes
  - Must understand hydrogeology and extents of impacted area
  - Do not stop half way



Preliminary Captain Jack Plan

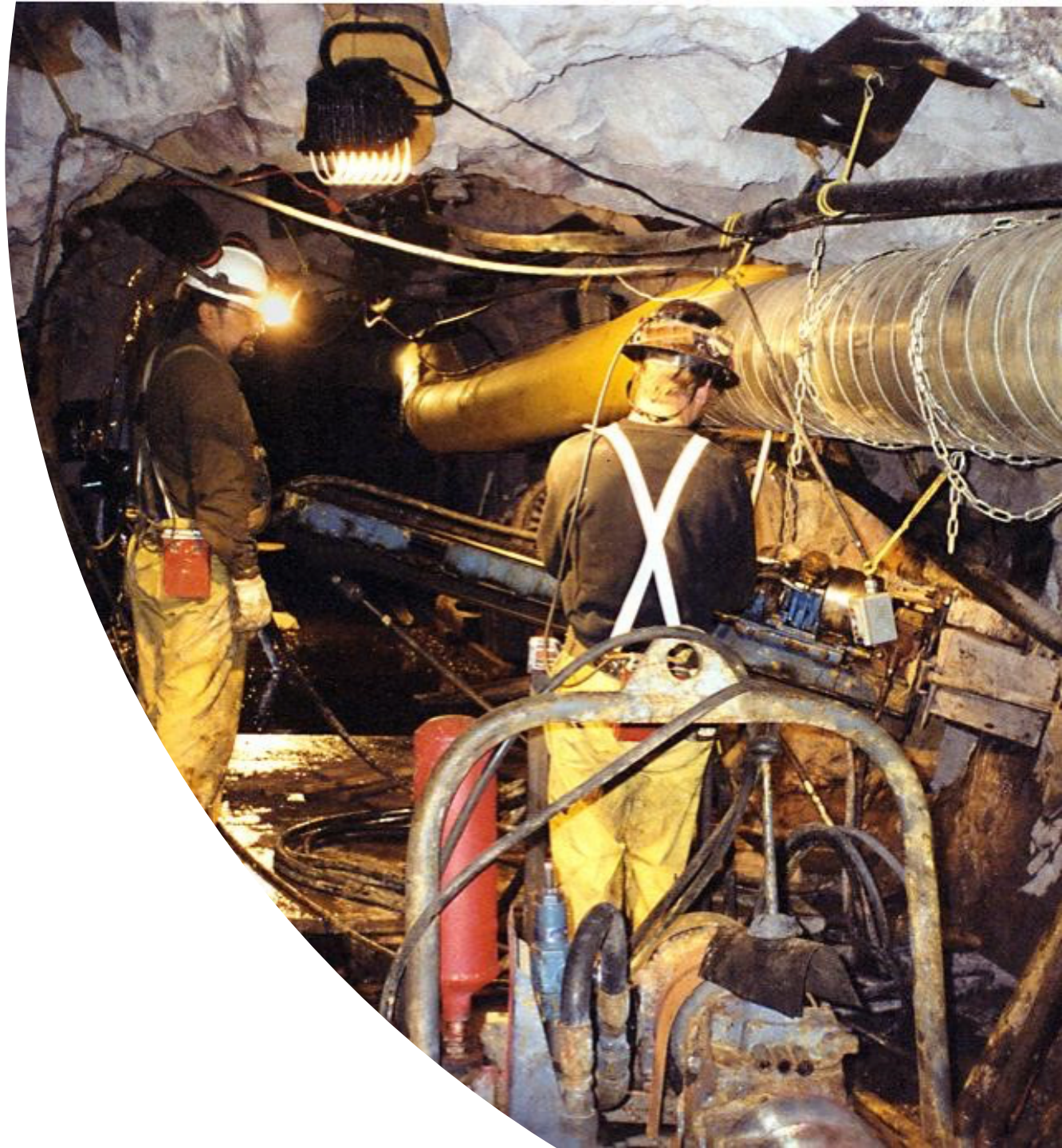
Bulkhead Design

- Constructability
  - Access
  - Materials
  - Temporary water diversion
- Piping and valves
  - Compatible pressure rating
  - Stainless steel
  - Regular discharge planned
  - Flow control (cavitation)?
- Testing pipes
  - pressure and sampling
- Consider all failure modes
  - Use high factors of safety

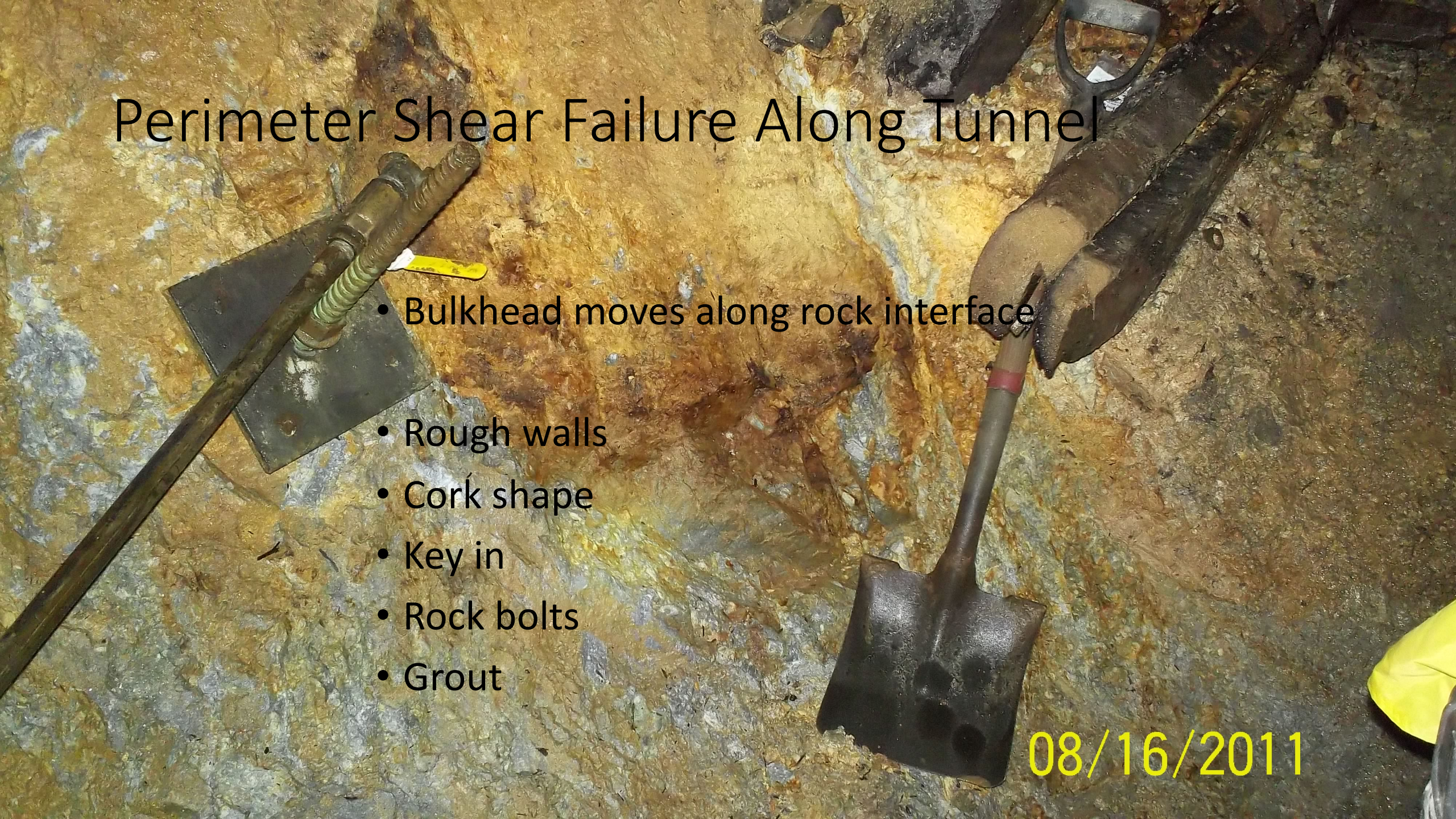
Hydraulic Jacking

- Water pressure opens joints in rock - leakage

- Locate under high cover
- Understand ground stresses
- Packer testing
  - Rock permeability under maximum design pressure



Perimeter Shear Failure Along Tunnel



- Bulkhead moves along rock interface

- Rough walls
- Cork shape
- Key in
- Rock bolts
- Grout

08/16/2011

Structural Failure

- Bulkhead fails through concrete in shear or bending

- Bulkhead length
- Reinforcing steel
- Quality concrete
- Consider earthquake water hammer loads

Concrete Degradation

- Acidic mine water chemically breaks down concrete

- Sacrificial thickness (length)
- Low permeability
- Type II/V cement + Flyash
- Place lime upstream

Seepage and Piping

- Excessive seepage past plug
  - Most likely mode of failure
  - Worst case = piping failure

- Geologic mapping, particularly joints and shears at and around bulkhead
- Grout ring at bulkhead, grouting of key joints upstream and downstream
- Long plug
- Post installation monitoring


10/04/2011

Bulkhead Myths

- Myth: Bulkheads are the right solution for every mine site
  - *Fact: poor choice if ground is too permeable or there are too many openings*
- Myth: Bulkheads will eliminate all mine water drainage
  - *Fact: can reduce flows perhaps by 90%*
- Myth: Bulkheads can be installed and forgotten (maintenance free!)
  - *Fact: need regular inspection and monitoring*
- Myth: Bulkheads only affect individual mines
  - *Fact: Must be part of holistic solution, can affect other mine workings through natural fractures*
- Myth: Bulkheads always improve water quality
  - *Fact: Typically yes, since flooded mines reduce oxygen for pyrite reaction but water quality may decrease as salts are mobilized (temporary storage)*

Bulkhead Risks

Real

- Leakage past bulkhead requires additional grouting or second bulkhead
- Water flows out of other mine workings (known and unknown)
- Seeps develop in surrounding area
- Water seeping past bulkhead still requires some form of treatment
- Piping failure around bulkhead
- Liability for flooding adjacent mines

Imagined

- Backed up water squirts out of the top of the mountain
- Bulkhead concrete blows out explosively and shoots out of the adit like a cannon ball

Integrating a Bulkhead Into the Site Plan

- One component of site solution
- Used in conjunction with
  - Sitewide monitoring and sampling
  - Flumes
  - Stream gages
  - Ponds
  - Passive treatment
  - In-situ treatment
  - Treatment plants?
- Bulkheads Can be used in various ways

Flow Control Structure

- No long term storage
- Manage surges or mine “burps”
- Adjust flows to what active or passive treatment can handle
- Requires cleaning and maintenance

Temporary Storage

- Use mine pool as underground reservoir to store water until it can be treated
- Allow time for in-situ treatment

Permanent Seal

- Return groundwater to pre-mining conditions (sort of)
- Treat seeps with passive means if needed
- Monitor bulkhead regularly (condition, head)
- In situ treatment

Post Bulkhead Installation

- Keep permanent access to bulkhead for monitoring
  - Seepage past bulkhead
  - Water level behind bulkhead
- Develop and execute filling and monitoring plan
  - Flow rates
  - Water chemistry
  - Bulkhead and adit
  - Surrounding mines
  - Surrounding seeps
  - Nearby streams

Bulkhead Inspection & Evaluation

- Condition of concrete face
- Condition of pipes and valves
- Condition of instruments
- Concentrated flows around bulkhead
- Concentrated flows downstream of bulkhead
- Condition of ground and support in access tunnel


Can you find the
valve in this picture?

Concluding Thoughts

- Due to the cost of indefinite treatment, bulkheads should be considered on most draining underground mine projects
- Regional and local Geology and Hydrogeology are key for evaluating if and where to install bulkheads
- Particular care must be taken in bulkhead design to evaluate local and area seepage
- Even if bulkhead valves remain open, they serve to regulate flow and limit damage from mine “burps” or set preferred mine pool level
- Seepage from ground due to bulkheads may still be improvement to water quality
- Bulkheads can be combined with in-situ treatment and treatment plant

Concluding Thoughts

- Bulkheads may or may not be the right solution for your site
- Bulkhead should only be installed after significant study and design
- Adjacent mines may be affected
- Monitoring and maintenance needed after installation

Christoph Goss, PhD, PE
Mining Engineer, Principal
christoph.goss@deereault.com

Joy Jenkins, PhD, PE
EPA Remedial Project Manager
jenkins.joy@epa.gov

Jeff T. Graves, PG
Director: Inactive Mine Reclamation Program
jeff.graves@state.co.us

The picture can't be displayed.