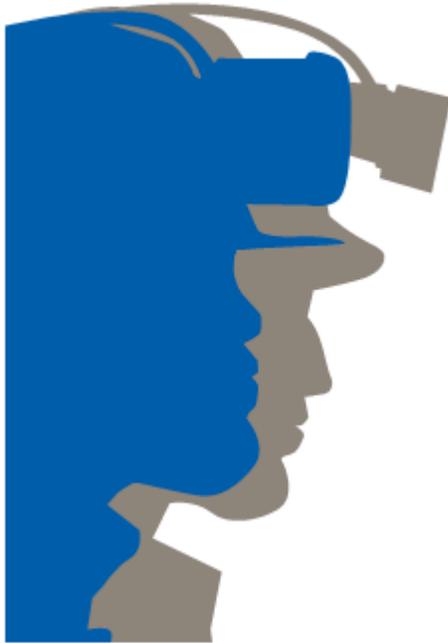


Corrosion in underground metal mines

Amy J. Chambers

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NIOSH Research Team:

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Research Collaborators:

**Hecla Mining Company
Montana Tech
Jennmar Corporation**

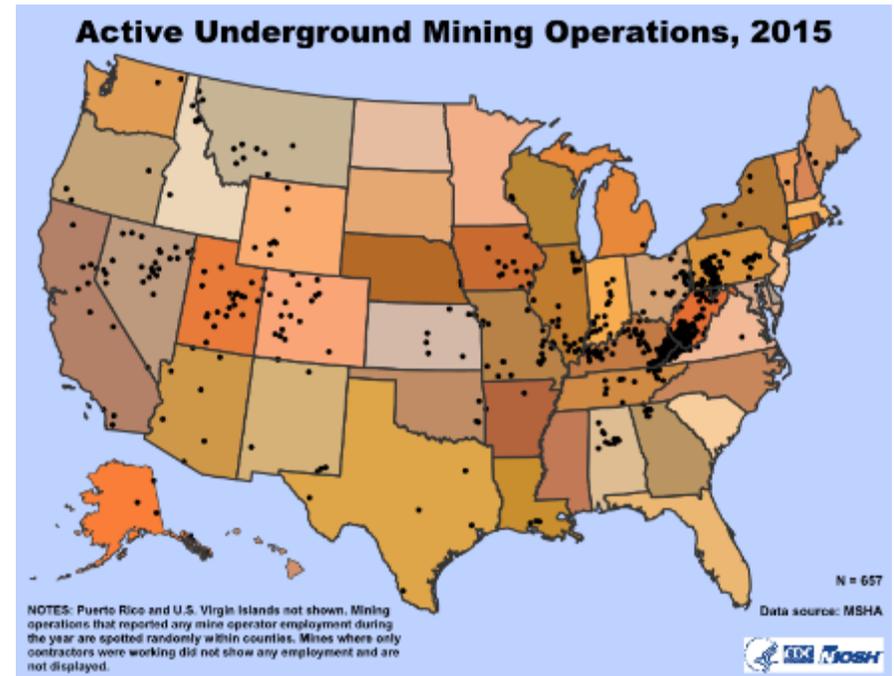


NIOSH Mining Program – www.cdc.gov/niosh/mining



NIOSH Mining Research Program

- Research seeks to work with industry and other collaborators to eliminate occupational diseases, injuries, and fatalities from the mining workplace
- Facilities in Spokane, WA and Pittsburgh, PA



- Spokane Mining Research Division (SMRD)
 - Focus on Western Mining safety and health
 - Metal Ground Control, Induced Seismicity, Automation Technology, and Miner Health teams
 - ~40 people split between the four groups

Outline

- Background
 - Corrosion in Mining
- Bolts and mesh
 - Field tests
 - Lab tests
- Future work
 - Pull tests
 - Non-destructive Testing





Low pH ground water

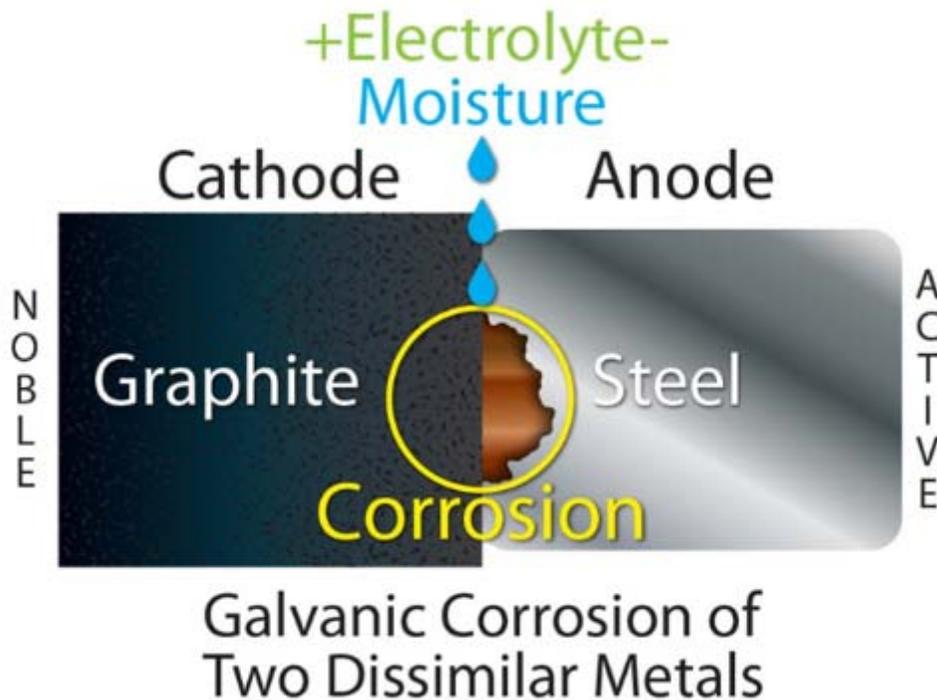
Juneau, Alaska



Some areas rehabilitated 6 months after installing ground support



Galvanic Rock Corrosion Mechanism

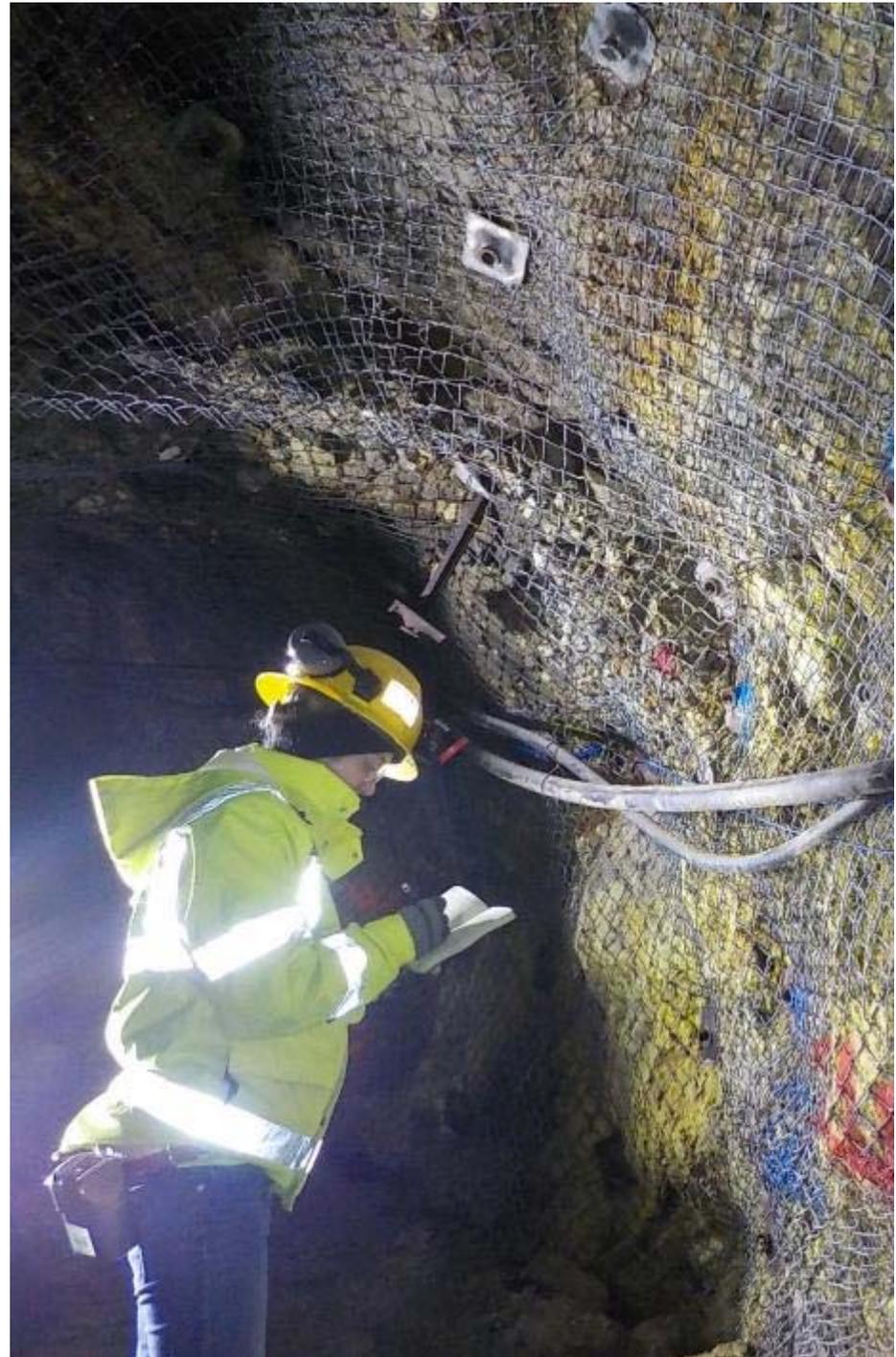


Galvanic Series

Metal	Volts vs Cu-CuSO ₄
Active or Anodic End	
Zinc	-1.10
Clean Carbon Steel	-0.50 to -0.80
Rusted Carbon Steel	-0.20 to -0.50
Carbon, Graphite	+0.30
Nobel or Cathodic End	

Field Tests

- Resistivity Measurements
- Coupons
- Time of wetness sensors
- MIC



Rock Mass Resistivity

- Electrical characteristic of the rock mass/soil/ground water which affects the ability of corrosion currents to flow through the electrolyte (rock mass, soil, groundwater)
- Function of moisture and the concentrations of ionic soluble salts – considered the most comprehensive indicator of a soil's corrosivity in the pipeline industry

Peabody, AW 2001, Control of Pipeline Corrosion 2nd Edition,
Bianchetti, RL (ed), NACE International Corrosion Society

Werner Array – Rock Mass Resistivity

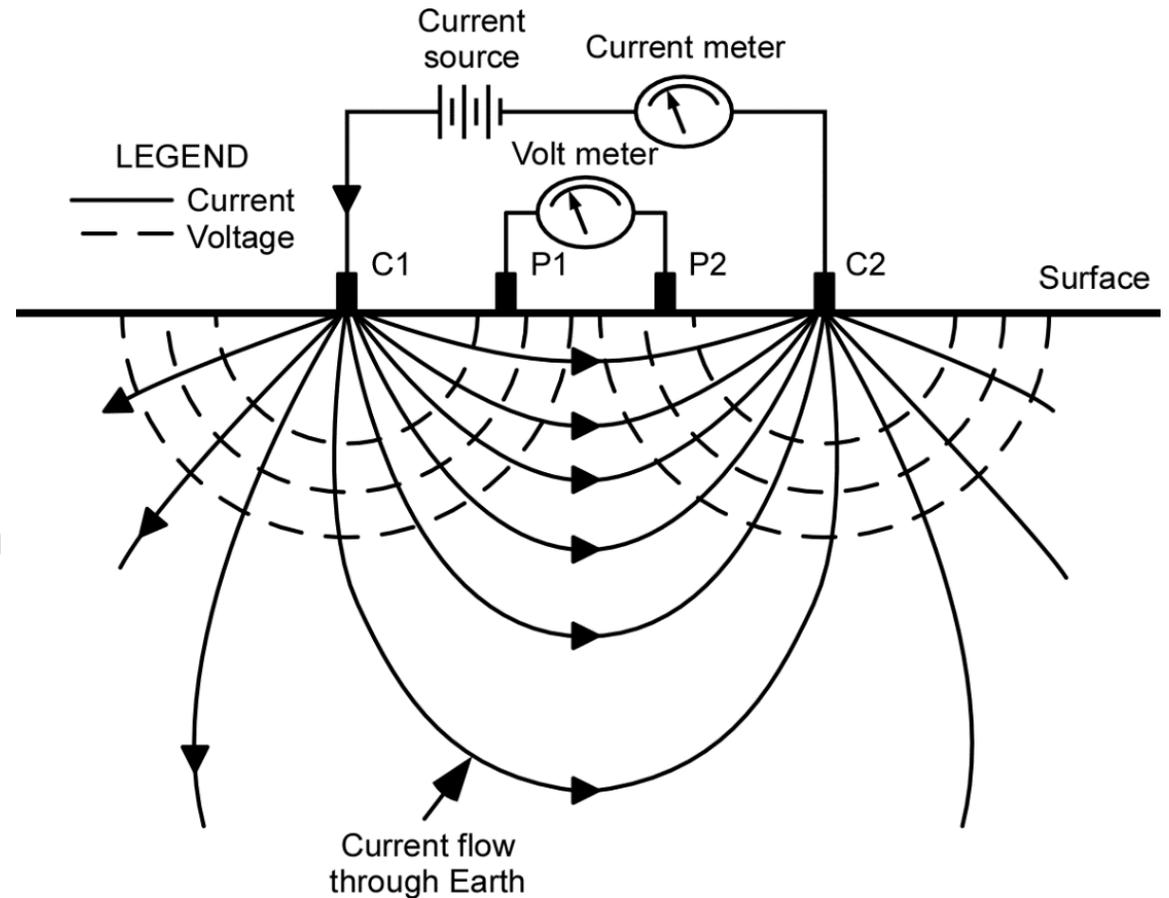
- Resistivity Measurement
- Four equally spaced electrodes
- C1 and C2 – Current electrodes
- P1 and P2 – Potential electrodes
- Depth of current penetration correlates to electrode spacing

$$\text{Resistivity} = 2\pi a \left(\frac{V}{I} \right)$$

a = electrode spacing

V = measured voltage

I = current



After ASTM D 6431: Standard Guide for using the direct current resistivity method for subsurface investigation

Rock Mass Resistivity Measurements

Montana



Measurement device designed by SMRD Electrical Engineer Carl Sunderman

Alaska



Classification system



C1: Negligible



C2: Localized



C3: Surface



C4: Advanced

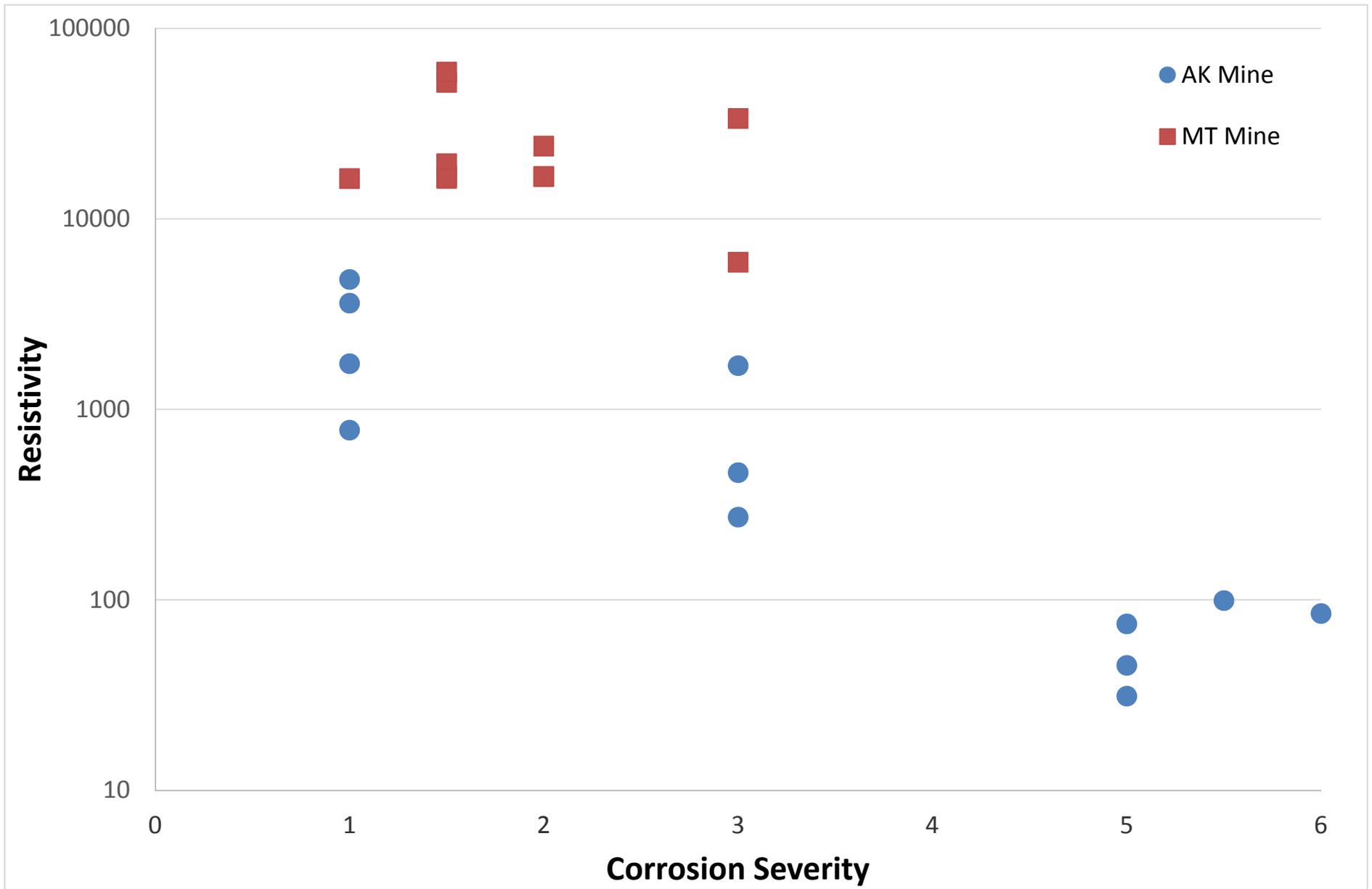


C5: Very Advanced



C6: Extreme

Resistivity data



Current Research – Field

Corrosion coupons – Alaska and Montana



Time of wetness and atmospheric monitoring in Montana mine

Sending Corrosion Sensor Data to the Cloud



Gateway (in mine)



Corrosion Sensors
Wireless Sensor Network
(in mine)



Researchers
Desktop/Phone





Microbial Influenced Corrosion

- Sulfate Reducing Bacteria (SRB) most common
- Reduction of sulfate to hydrogen sulfide leads to increased corrosion
- $\text{SO}_4^{2-} \longrightarrow \text{H}_2\text{S}$



Lab Tests

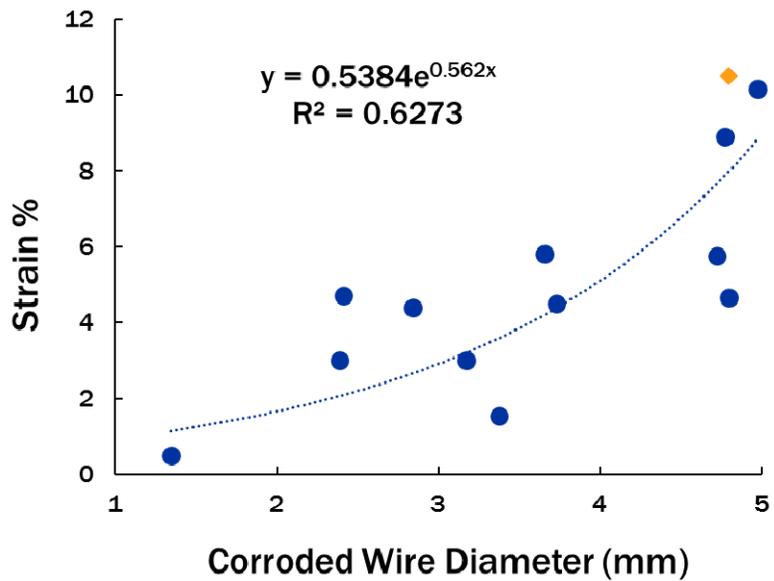
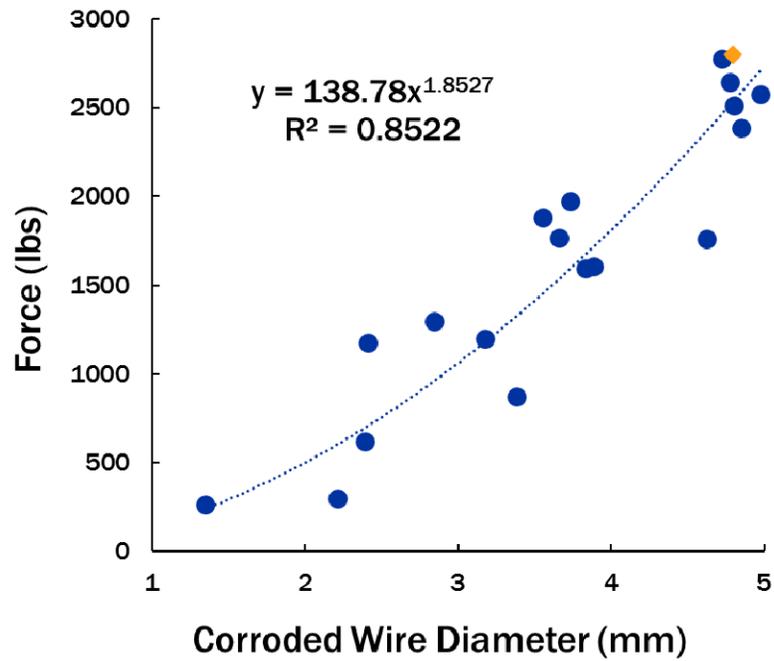
- Laboratory tension testing of ground support
 - Multiple samples with a range of corrosion severity
- Tension bolt drip system
- Humidity room coupons



Tension Pull Tests



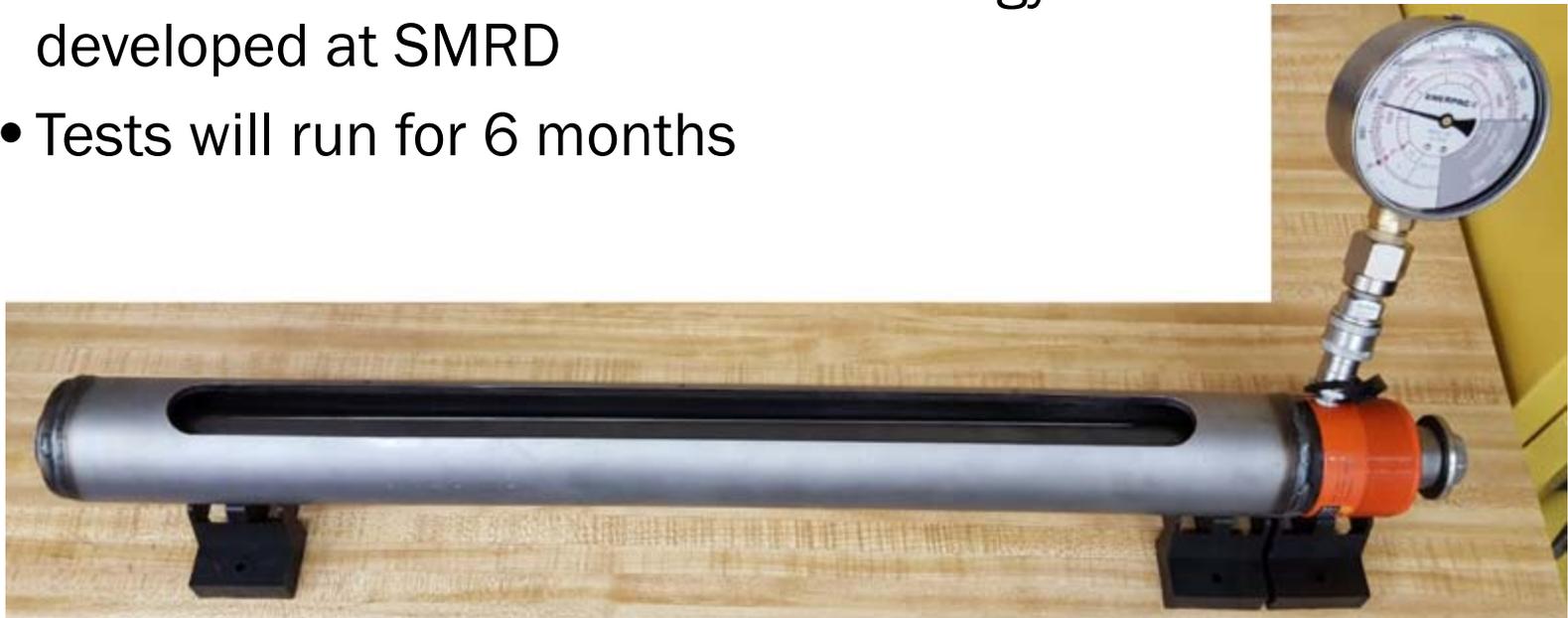
Wire Mesh Pull Tests



Tensioned bolt drip system

Development of tensioned rock bolt testing

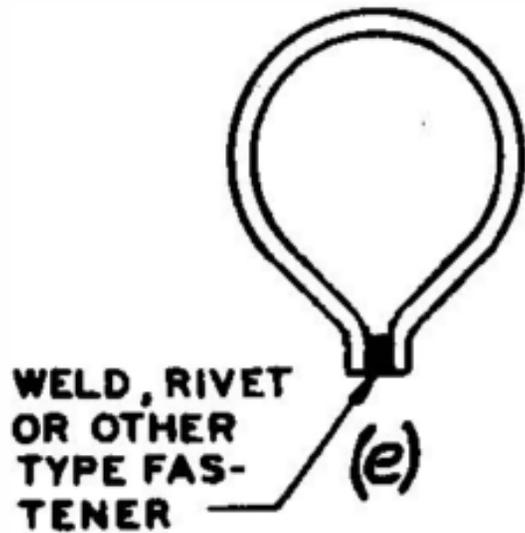
- Bolts donated by Jennmar
- Load Frames built in house – set out for corrosion resistant coating (Precision Dip Coating LLC)
- Frames built and scratch methodology developed at SMRD
- Tests will run for 6 months





Current Research - Lab

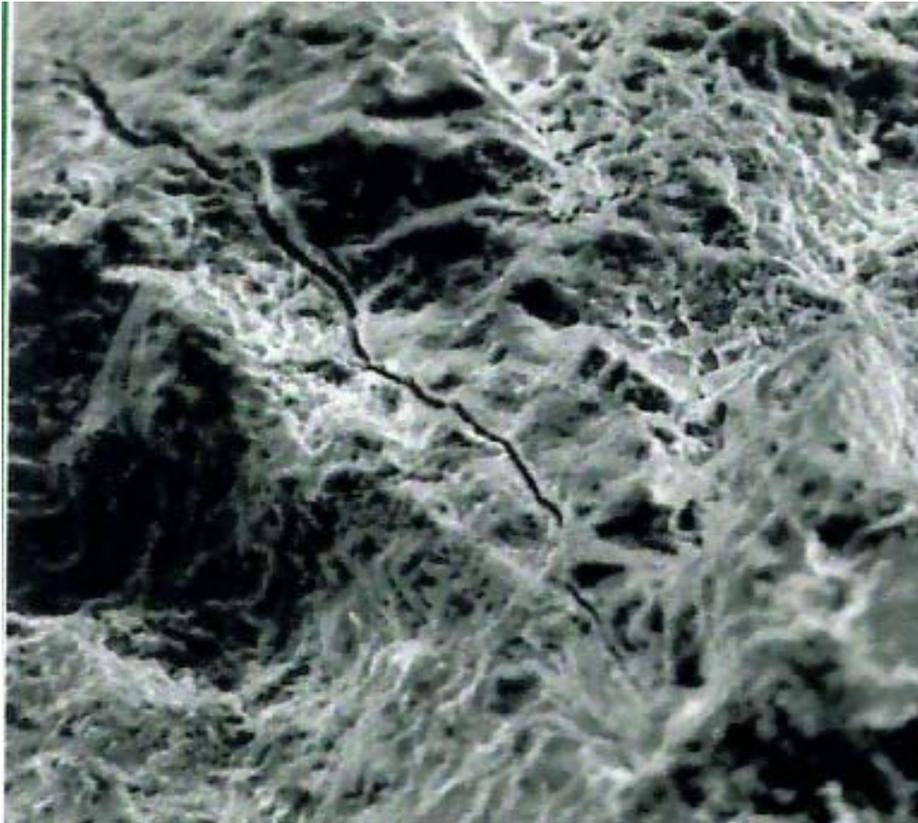
- Fog room bolt coupons 18 sets in 16 different rock types with 2 control sets from Alaska Mine



- Expected time of results: 3, 6, and 12 month test series

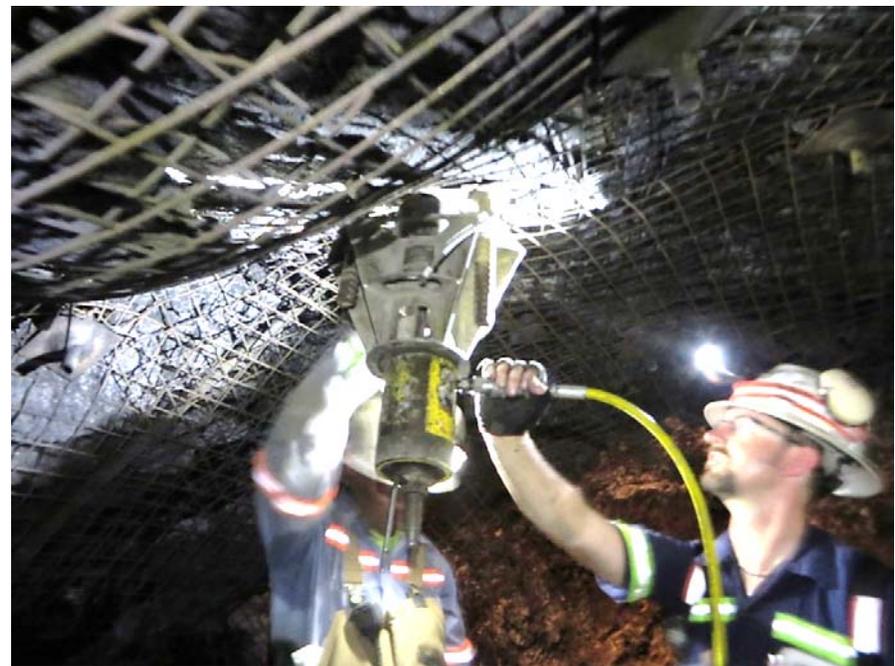
Lab coupons

- Mass loss
- Rockwell hardness
- SEM analysis



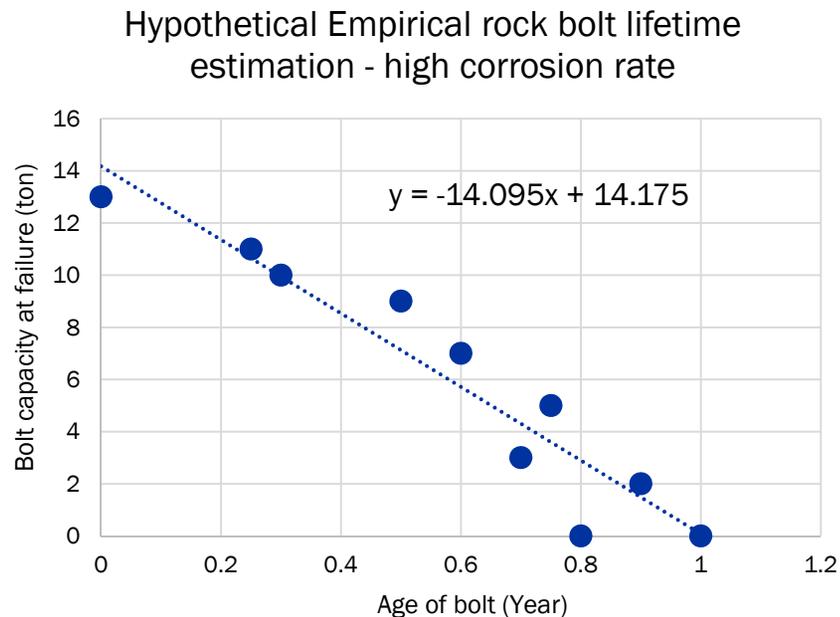
Estimation of Rock Bolt Longevity – Engineering Practice/collaborator

- Empirical study
- Estimate corrosion rate in terms of bolt capacity
- Pull bolts to failure with rock bolt pull tester
 - Bolts of different ages – install own or use mine bolts
 - Different corrosive environments (corrosion rates)



Estimation of Rock Bolt Longevity – Engineering Practice/collaborator

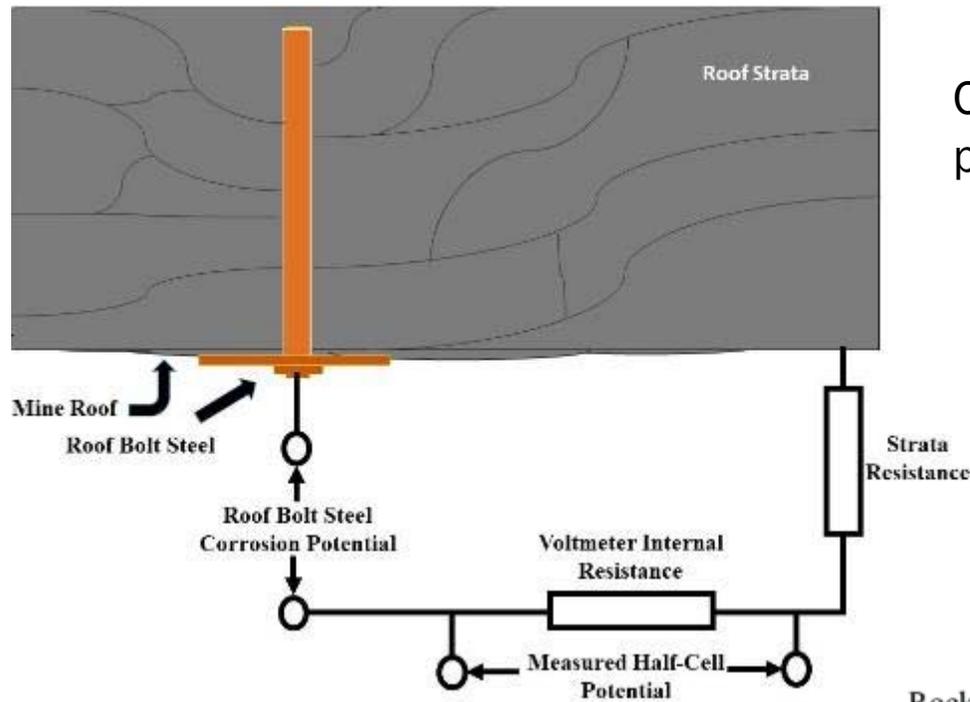
- Goal: produce design chart to estimate bolt life
 - Engineering tool decide use inexpensive (corrosion prone)
 - Vs. cost effective (?) to install expensive corrosion resistant bolts
 - Safety: life of bolt- better estimates of rehab schedule- reduce corrosion related fall-of-ground (FOG)



Hypothetical data

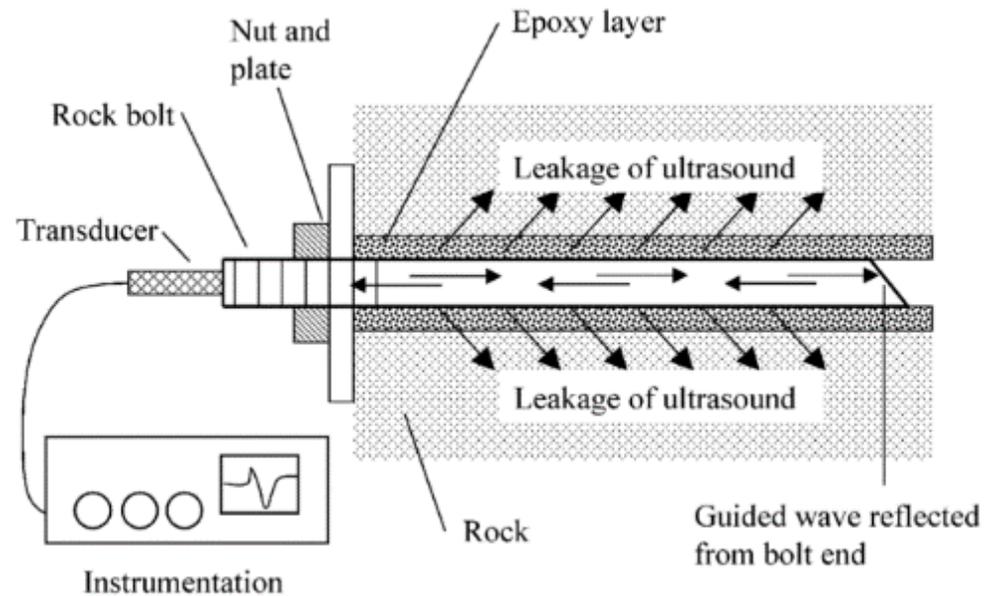


Non Destructive Monitoring



Circuit schematic of the half-cell potential technique

Ultrasonic measurement



Shotcrete overlay

- Shotcrete encasement of non-submerged support
- Studies of corrosion propagation through shotcrete in western underground metal mines





Thank you



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NIOSH Mining Program – www.cdc.gov/niosh/mining

