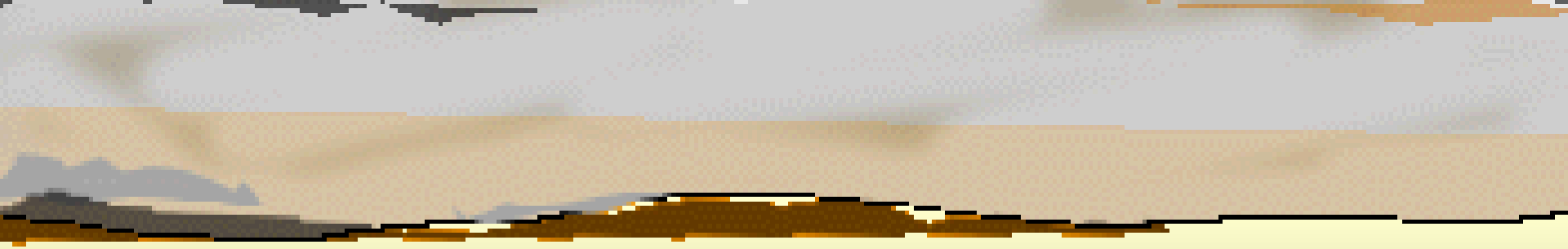


Corrosion Cells In Action

Chapter 1

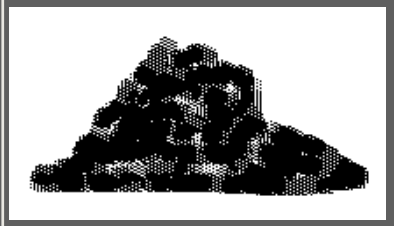
Appalachian Underground Corrosion Short Course

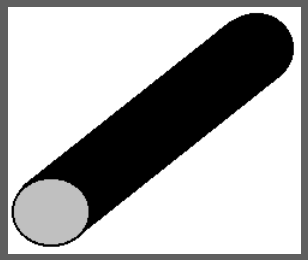
Introduction

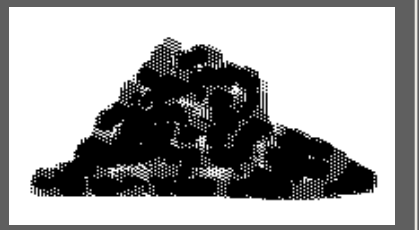
- Review of Basic Concepts
- The Chemistry of Corrosion
- Electromotive/Galvanic Series
- Galvanic Corrosion Examples
- Corrosion Cells in Action

Why are we Here?

- Corrosion Costs
  - 440 Billion Annually
- Why?







Iron Ore (oxide) → Refine → Products (Pipe) → Corrosion (oxide)

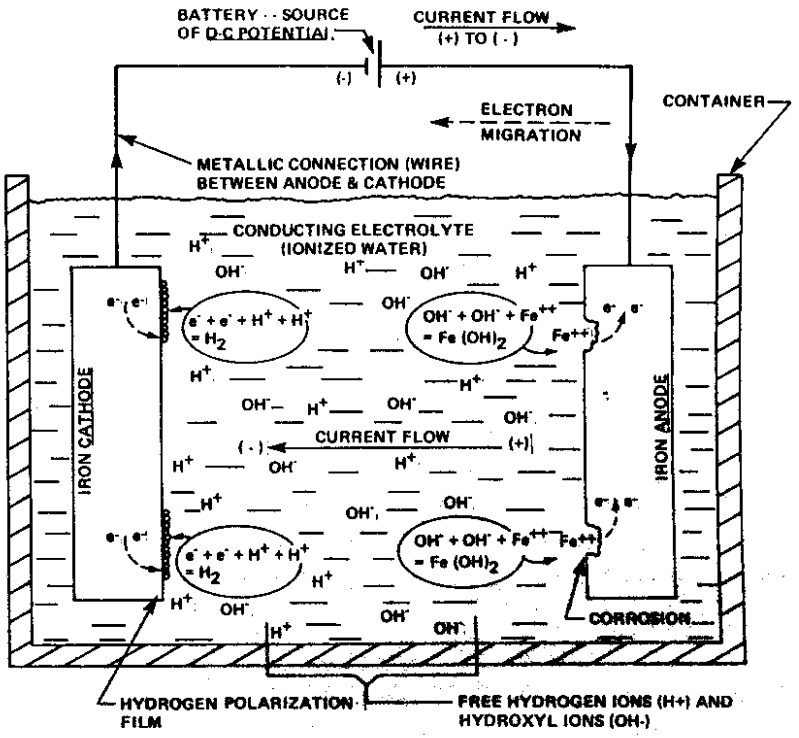
Basic Concepts

- Four Essential Elements of Corrosion Cell
  - Anode
  - Cathode
  - Conductive Electrolyte
    - In contact with both anode and cathode
  - Metallic Conductor
    - Connecting anode and cathode

Basic Concepts

- Anode
  - Discharges Ions (Oxidation Reactions)
  - Location of Current Discharge
  - Corrodes
- Cathode
  - Collects Ions (Reduction Reactions)
  - Location of Current Pickup
  - Protected

Basic Concepts



CORROSION IN ACTION
FIGURE 1

Anodic Reaction - Corrosion

$Fe \rightarrow Fe^{++} + 2e^{-}$ = Oxidation

Cathodic Reaction - Protection

$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$ = Reduction

Basic Concepts

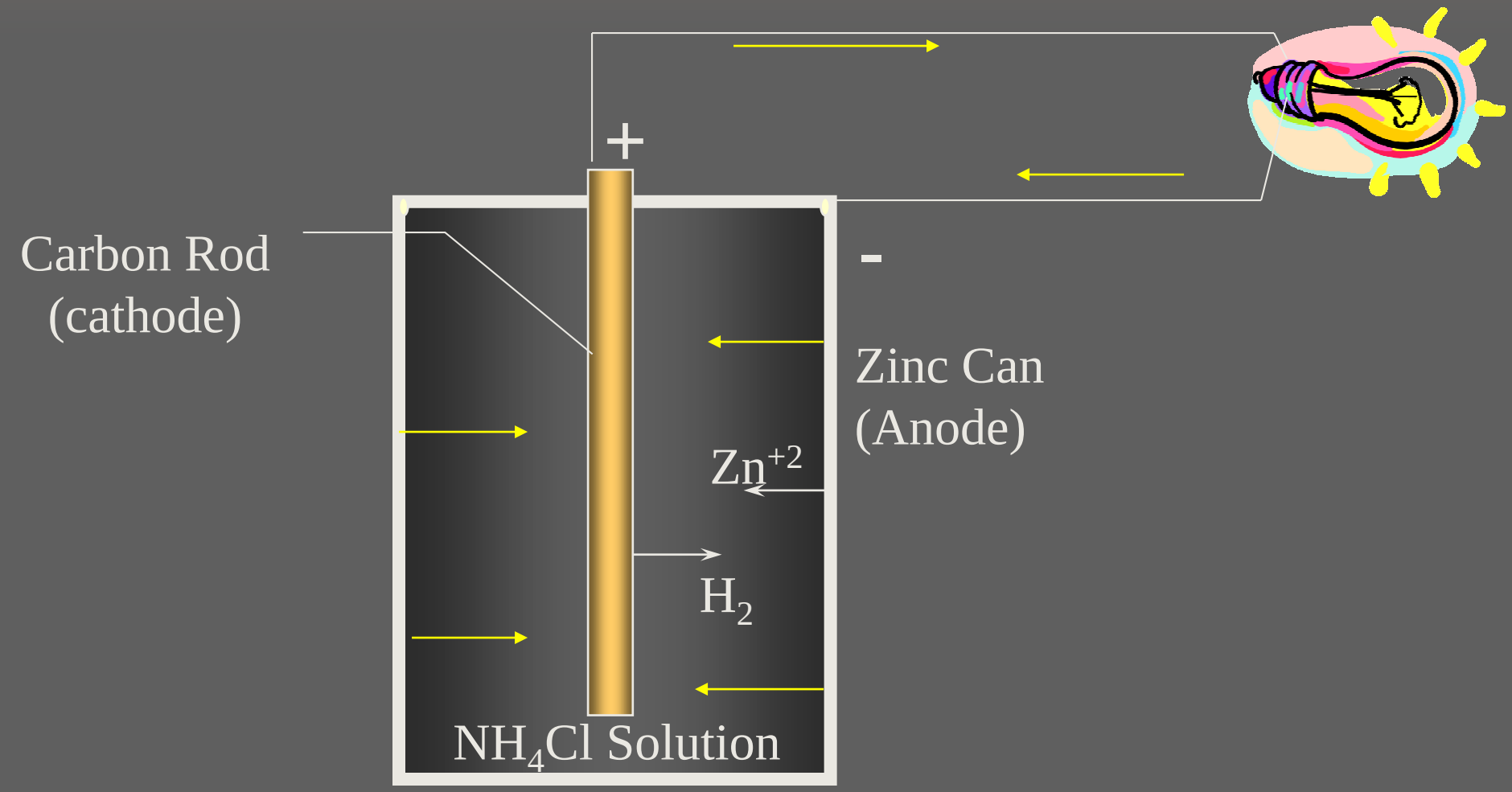
- Combined Reactions

$$Fe + 2H_2O \longrightarrow Fe^{++} + 2H^{+} + 2(OH)^{-}$$

$$Fe^{++} + 2(OH)^{-} \longrightarrow Fe(OH)_2$$

Ferrous Hydroxide

Dry Cell Example

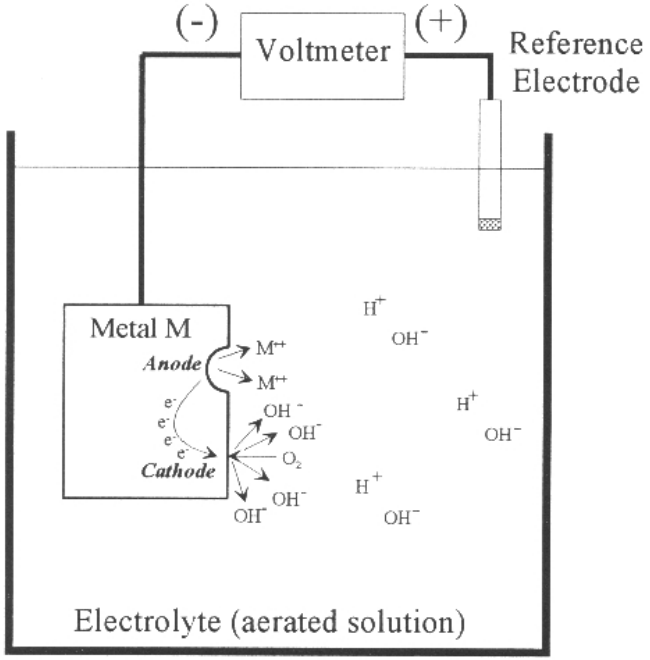


Electromotive Force

METAL	VOLTS
Magnesium	-2.37
Aluminum	-1.66
Zinc	-0.76
Iron	-0.44
Tin	-0.14
Lead	-0.13
Hydrogen	0.00
Copper	+0.34 to +0.52
Silver	+0.80
Platinum	+1.20
Gold	+1.50 to +1.68

MEASURE WITH RESPECT TO HYDROGEN REFERENCE ELECTRODE

Potential Measurements



Anode Reaction:

$$M \longrightarrow M^{++} + 2e^-$$

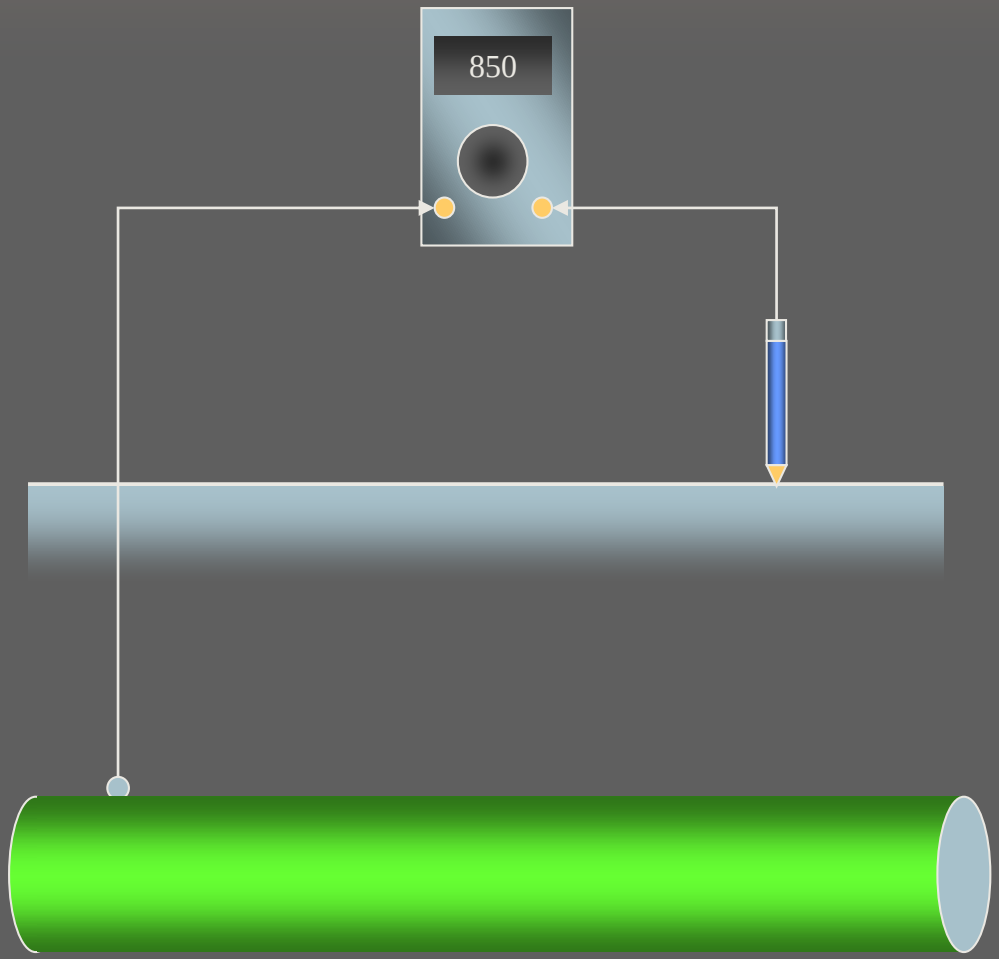
Cathode Reaction:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

Overall Reaction:

$$2M + O_2 + 2H_2O \longrightarrow 2M^{++} + 4OH^-$$

Potential Measurements



Cathodic

Anodic

Practical Galvanic Series in Seawater

Noble (+)

Platinum
Gold
Graphite
Titanium
Silver
Chlorimet 3 (62 Ni, 18 Cr, 18 Mo)
Hastelloy C (62 Ni, 17 Cr, 13 Mo)
18-8 Mo stainless steel (passive)
18-8 stainless steel (passive)
Chromium stainless steel 11-30% Cr (passive)
Inconel (passive) (80 Ni, 13 Cr, 7 Fe)
Nickel (passive)
Silver Solder
Monel (70 Ni, 30 Cu)
Cupronickels (60-90 Cu, 40-10 Ni)
Bronzes (Cu-Sm)
Copper
Brasses (Cu-Zn)
Chlorimet 2 (66 Ni, 32 Mo, 1 Fe)
Hastelloy B (60 Ni, 30 Mo, 6 Fe, 1 Mn)
Inconel (active)
Nickel (active)
Tin
Lead
Lead-tin solders
18-8 Mo stainless steel (active)
18-8 stainless steel (active)
Ni-Resist (high Ni cast iron)
Chromium stainless steel, 13% Cr (active)
Cast iron
Steel or iron
2024 aluminum (4.5 Cu, 1.5 Mg, 0.5 Mn)
Cadmium
Commercially pure aluminum (1100)
Zinc
Magnesium and magnesium alloys

Active (−)

Anodic

METAL	VOLTS
Commercially pure magnesium	-1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% Zinc)	-1.05
Commercially pure aluminum	-0.8
Mild Steel (clean and shiny)	-0.5 to -0.8
Mild Steel (rusted)	-0.2 to -0.5
Cast Iron (not graphitized)	-0.5
Lead	-0.5
Mild Steel in Concrete	-0.2
Copper, brass, bronze	-0.2
High Silicon Cast Iron	-0.2
Mill Scale on Steel	-0.2
Carbon, Graphite, Coke	+0.3

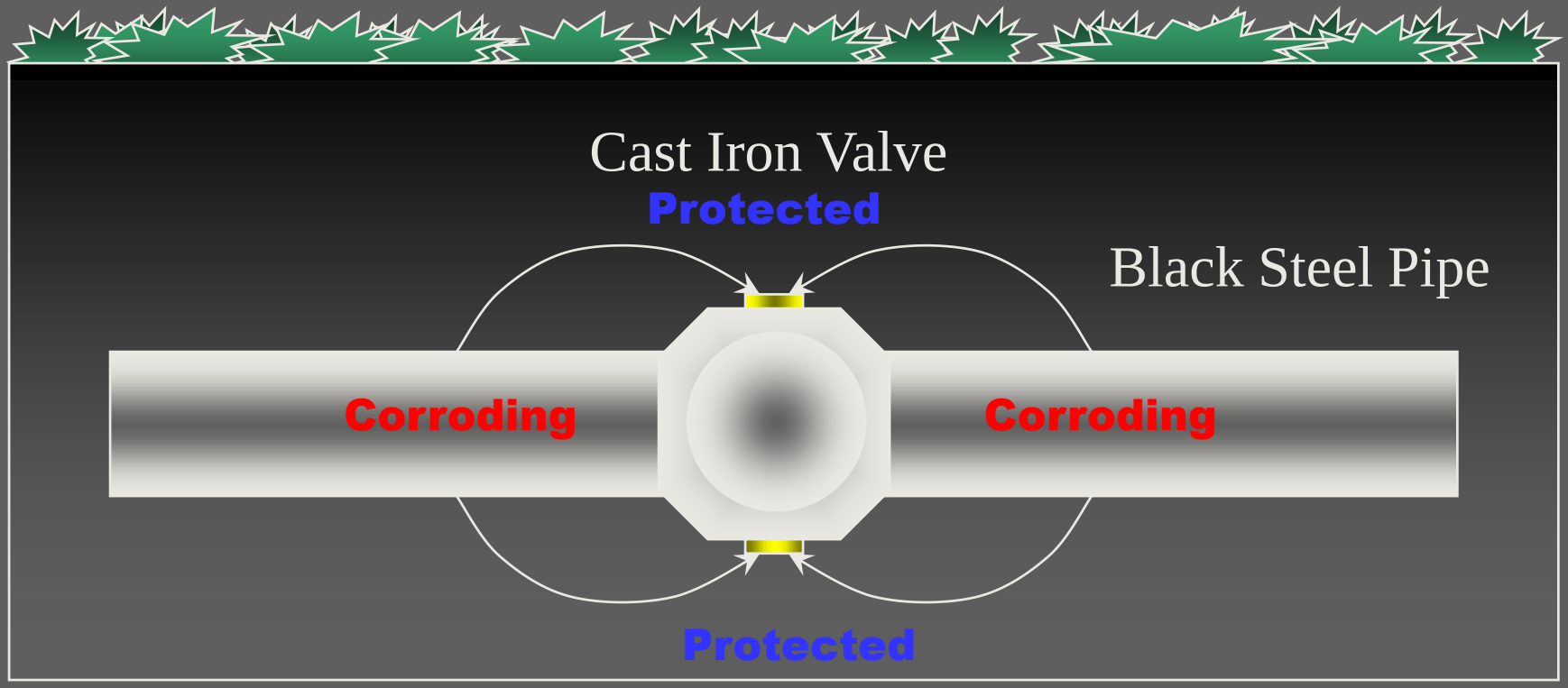
Cathodic

Practical Galvanic Series in Soil

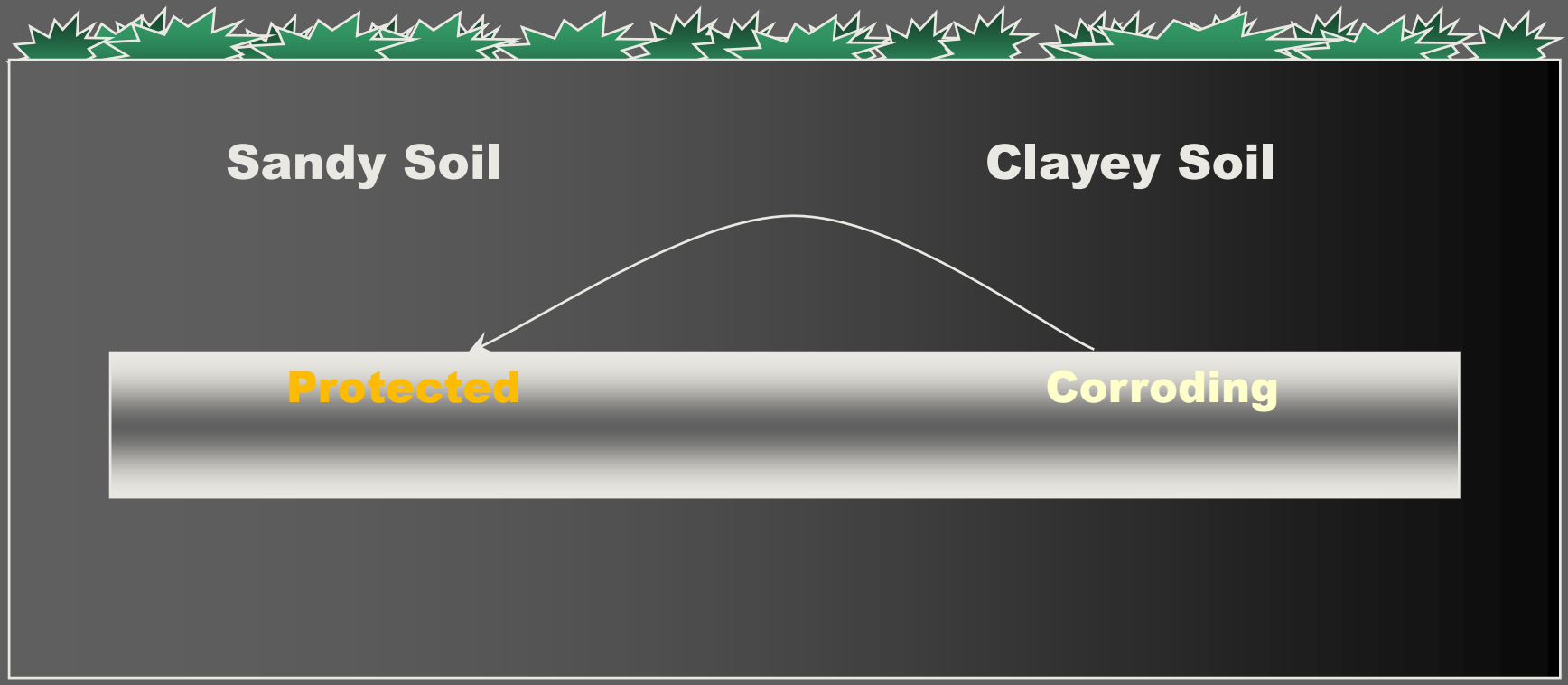
Galvanic Corrosion Examples

- Dissimilar Metal Couple
- Non-Homogeneous Soils
- Differential Aeration/Chemistry
- Dissimilar Surface Conditions
- Stray Current
- Effect of Stress

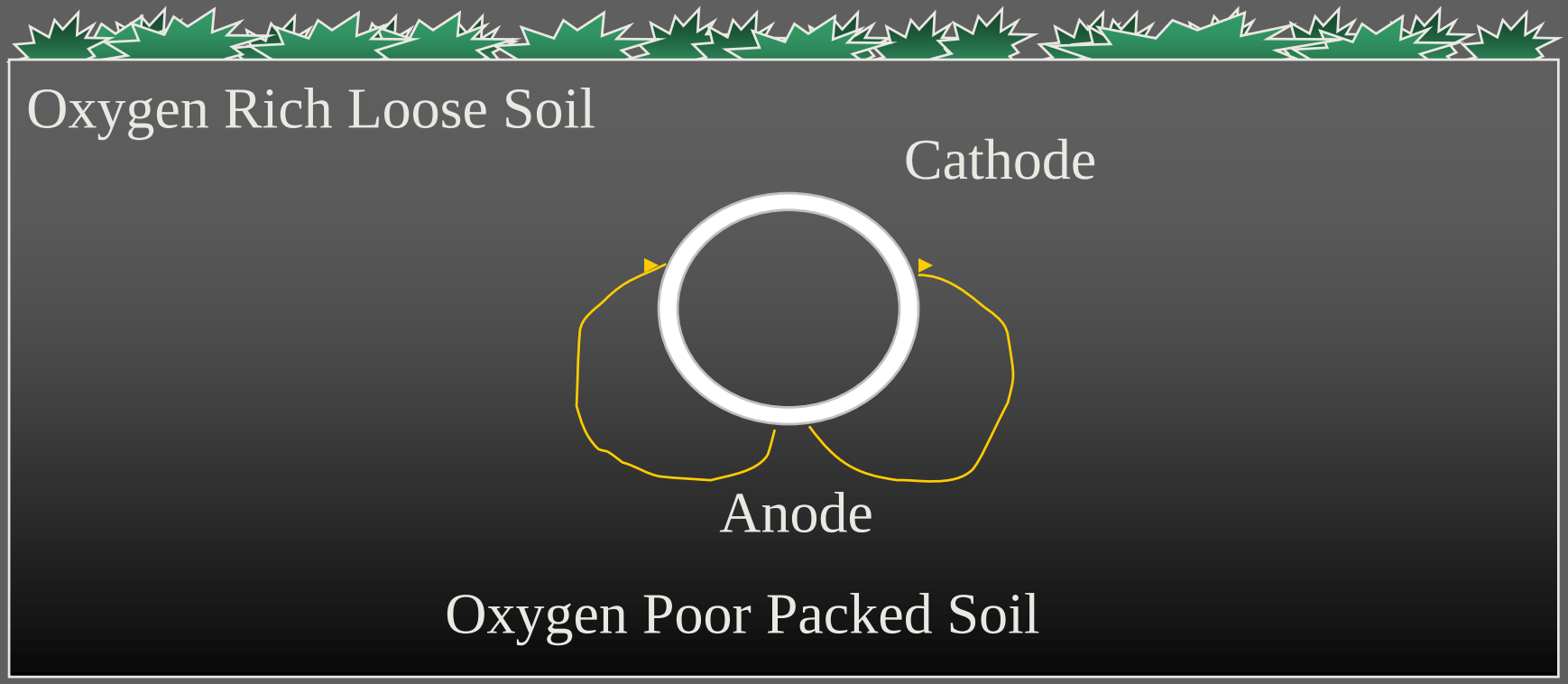
Dissimilar Metal Couple



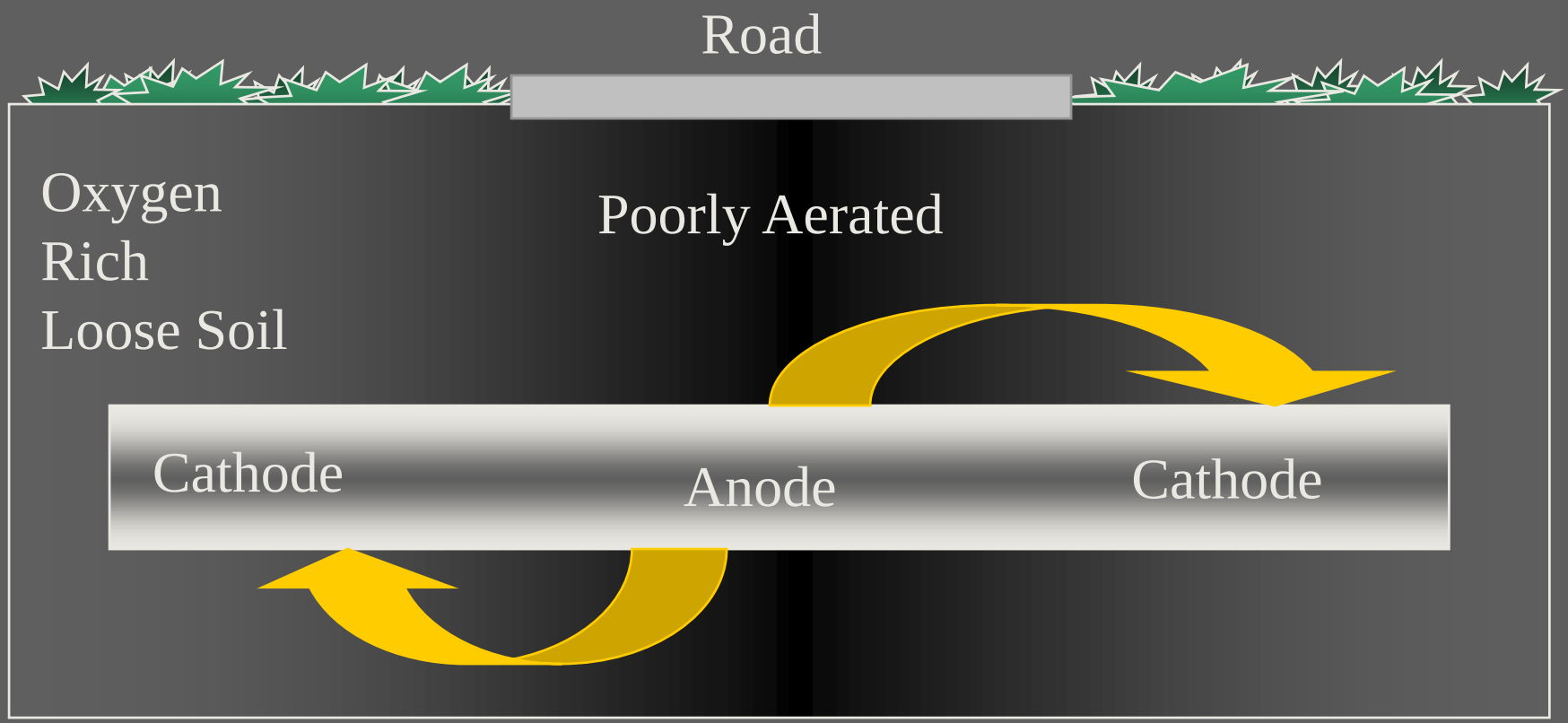
Non-Homogeneous Soil



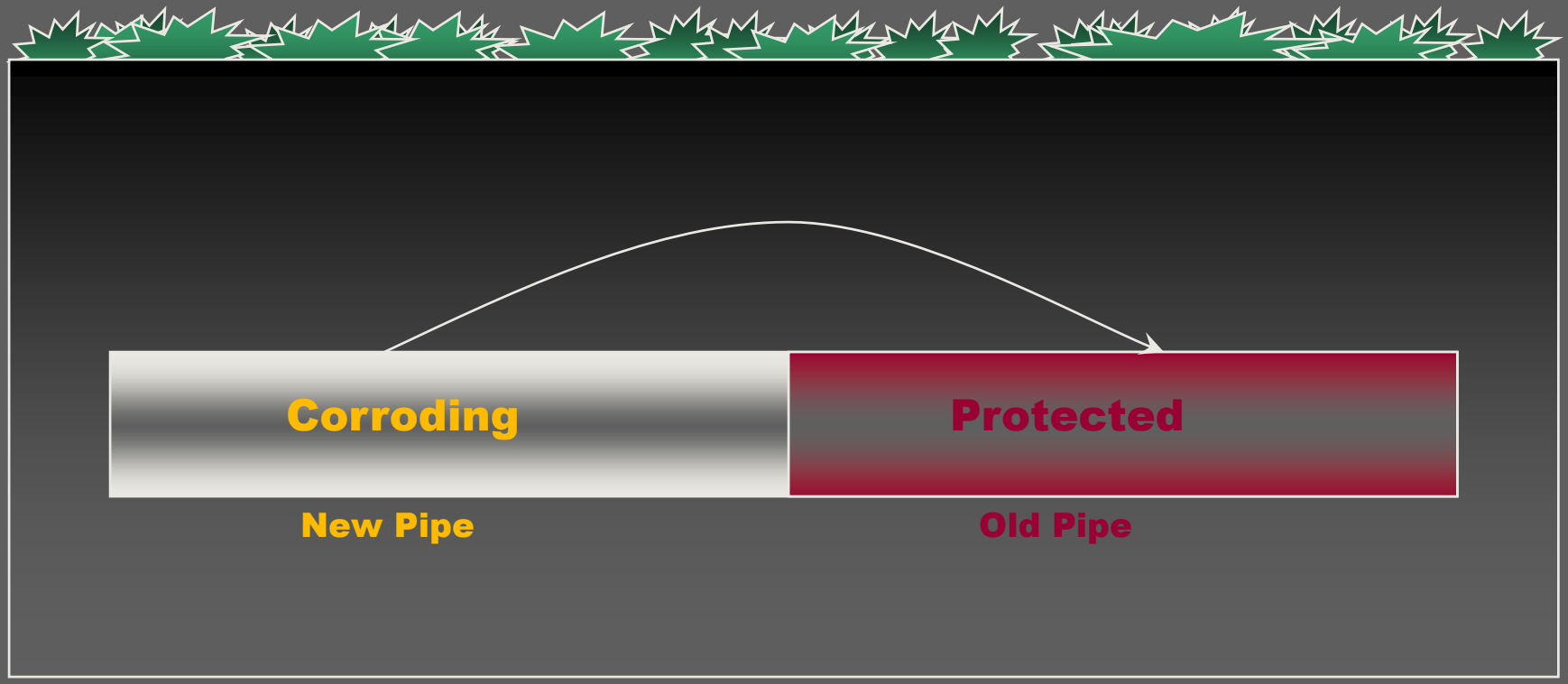
Differential Aeration



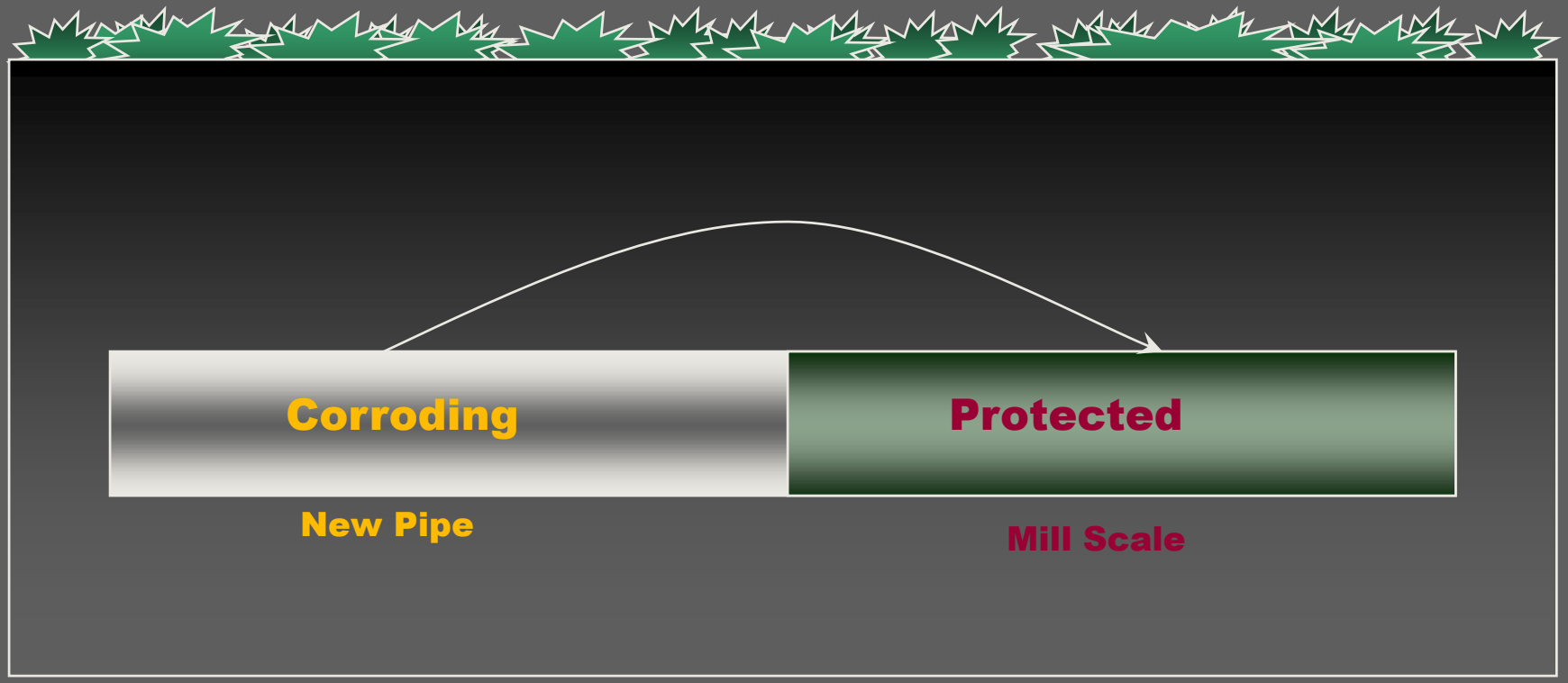
Differential Aeration



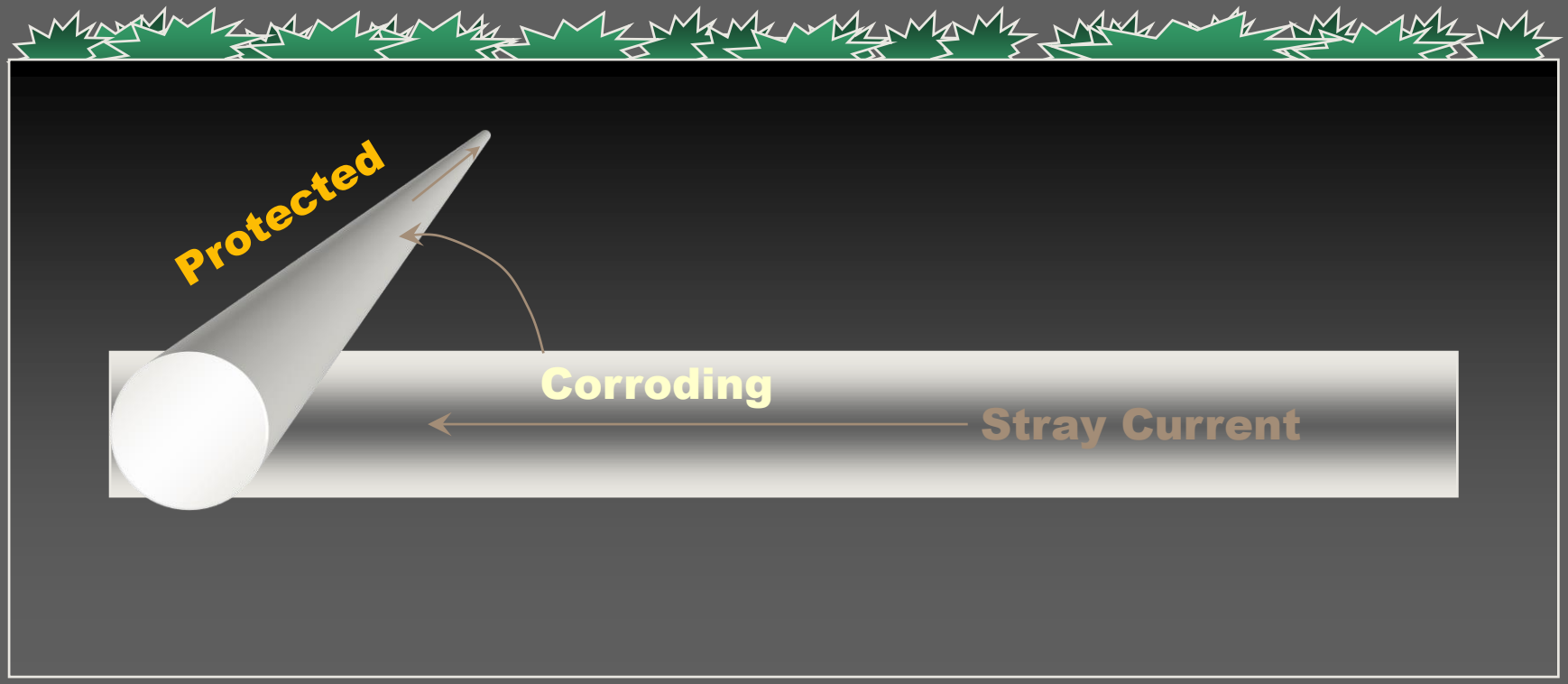
Dissimilar Surface Conditions



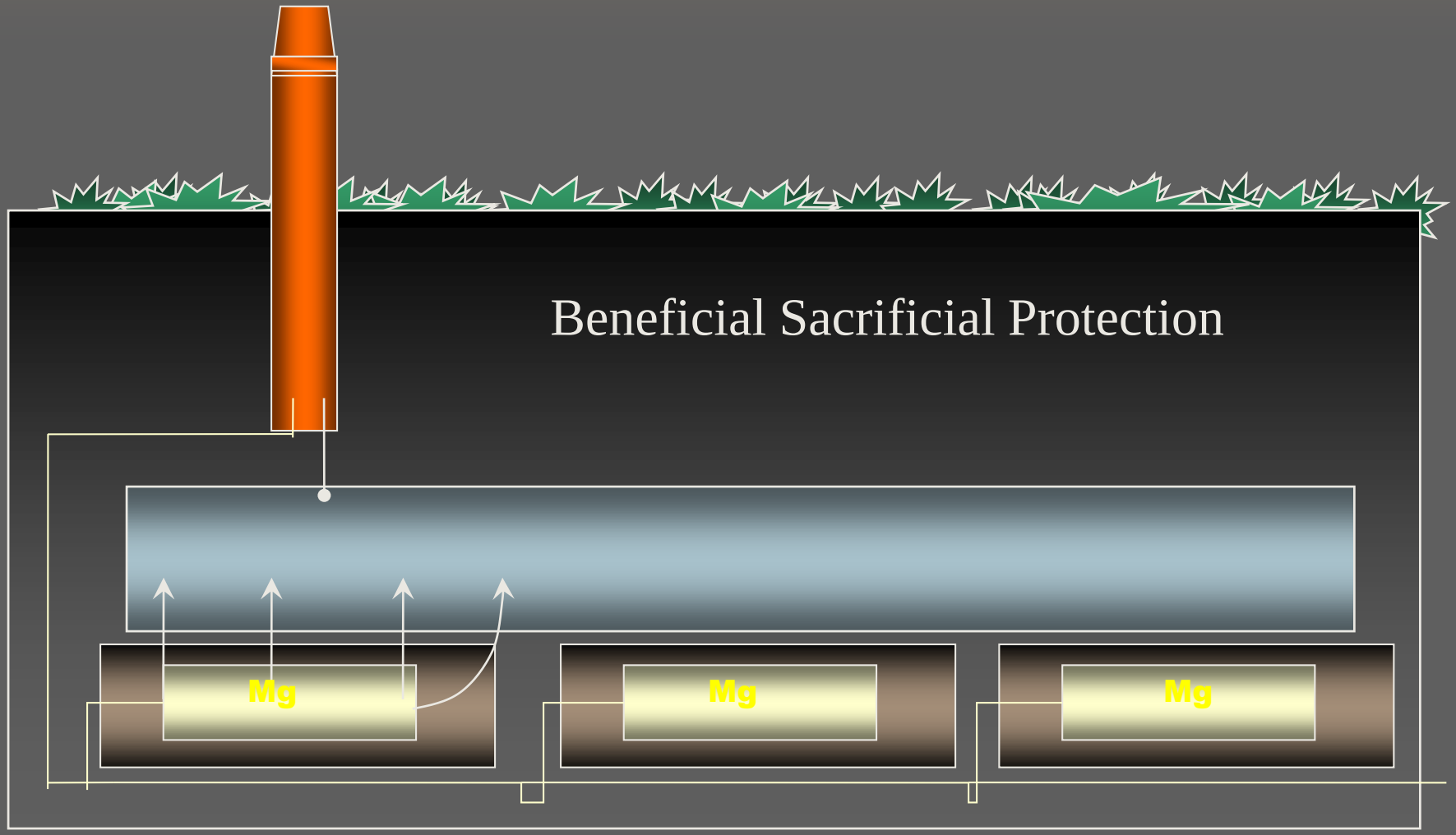
Dissimilar Surface Conditions



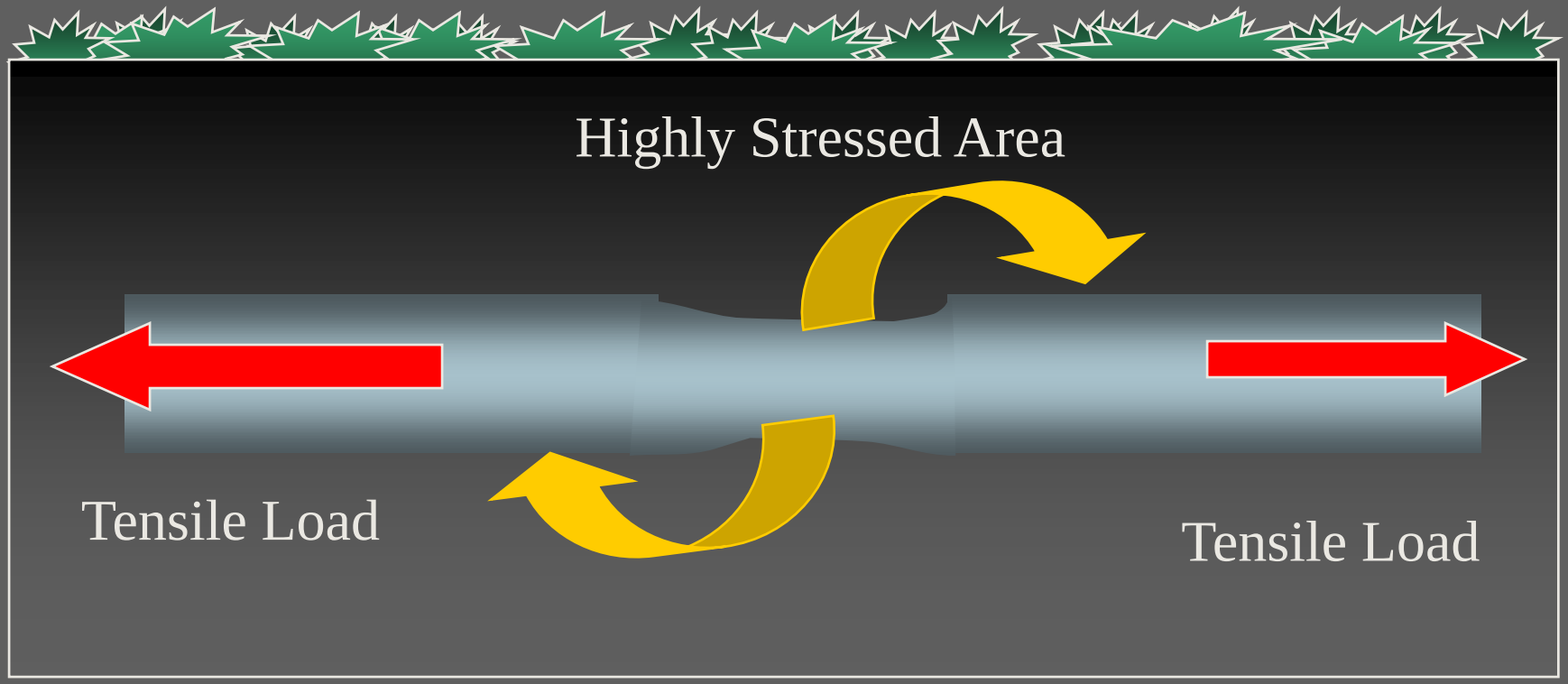
Stray Current



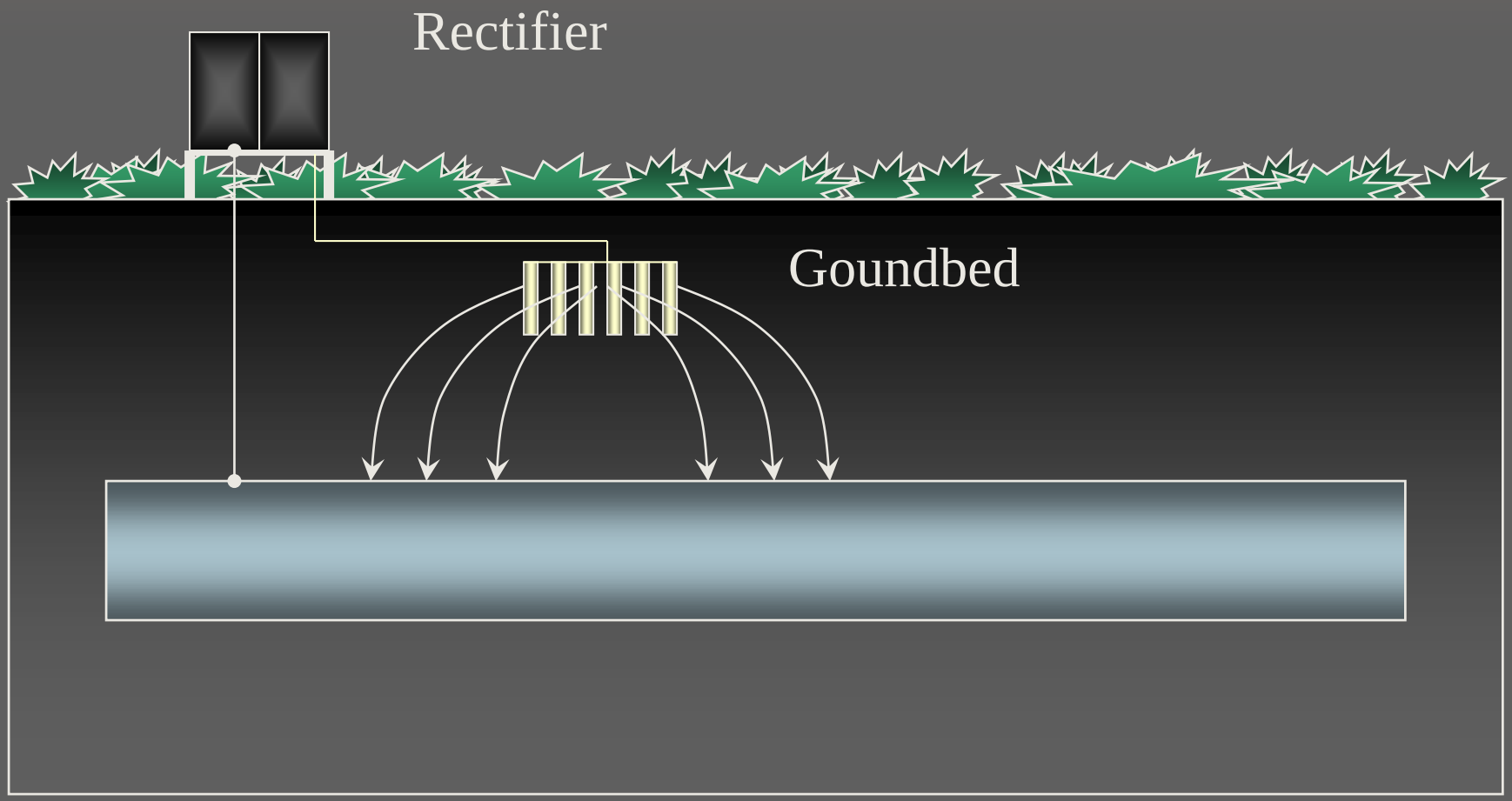
Dissimilar Metal Couple



Effect of Stress



Cathodic Protection



Corrosion Cells

- Developed by Col George. C. Cox
- How do they Work?
  - Differentiate Anodic and Cathodic areas with indicating solutions
    - Anodic Areas – Potassium Ferricyanide
      - Turns Bluish Green in the presence of Fe^{++}
    - Cathodic Areas – Phenolphthalein
      - Turns bright pink or crimson as pH increases (OH^-)

Corrosion Cells

- On-Screen projection to show effects