Corrosion Fundamentals

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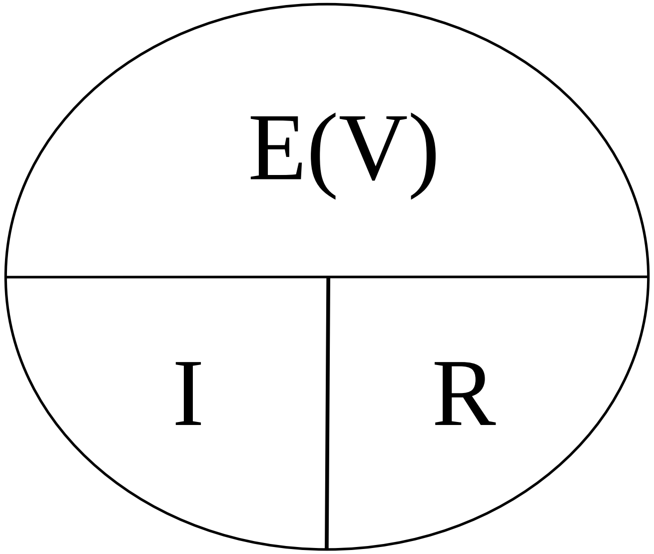
Appalachian Underground Corrosion Short Course

BASIC ELECTRICITY REVIEW

Three Electrical Quantities – Ohm's Law

- I= Current Flow
- E= Driving Force
- R= Resistance



WHAT IS CORROSION?

- CORROSION IS THE DETERIORATION OF A MATERIAL BY REACTION WITH ITS ENVIRONMENT
  - METALS
  - POLYMERS
  - CONCRETE
  - WOOD
- WE WILL BE TALKING ABOUT METALS IN A PIPELINE ENVIORNMENT

COST OF CORROSION

- According to a study done by NACE in 2016, the annual cost of corrosion across the world is $2.5 Trillion.
- The study found that implementing corrosion prevention could result in a savings of $375-875 Billion

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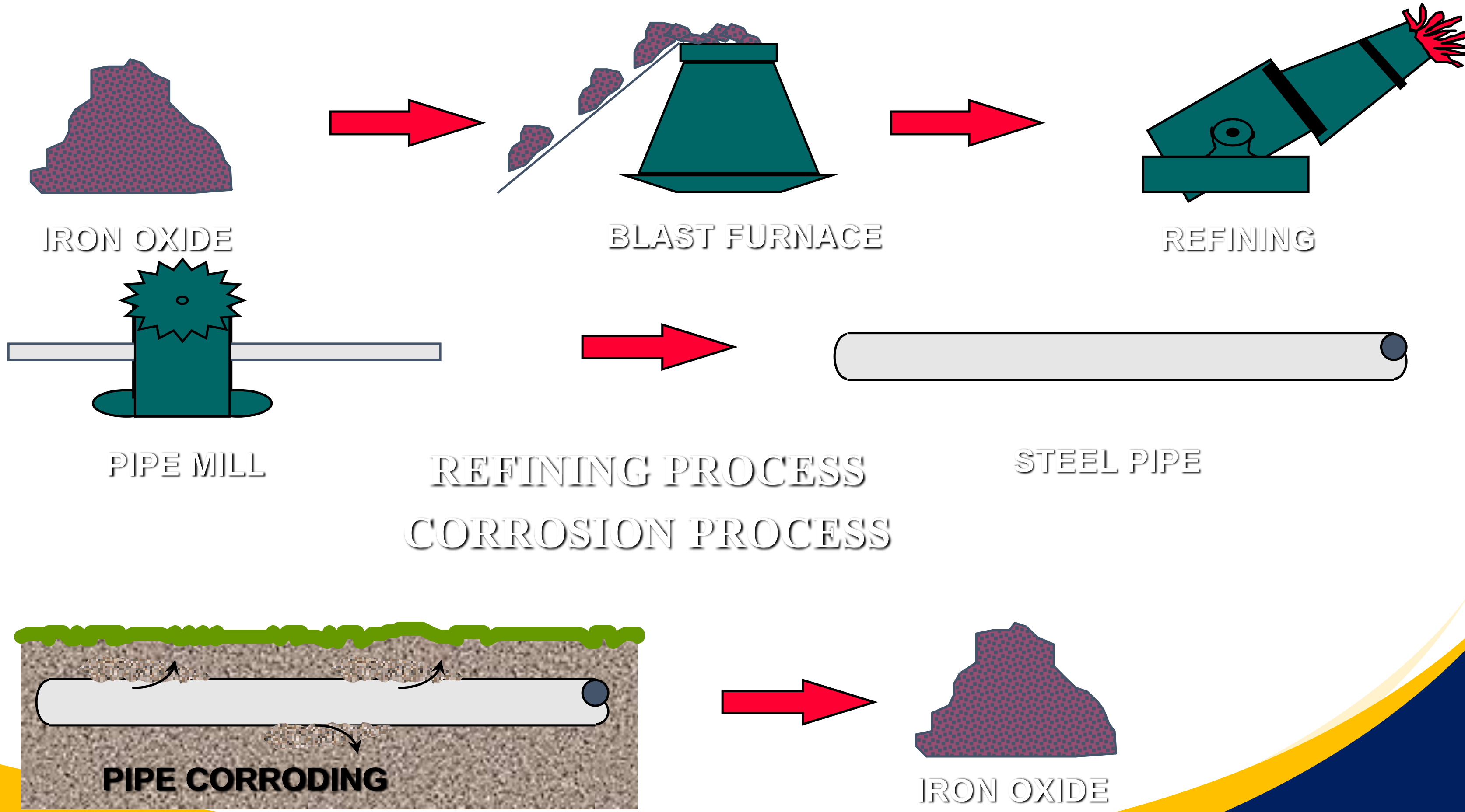
WHAT IS CORROSION?

- CORROSION IS THE DETERIORATION OF A MATERIAL BY REACTION WITH ITS ENVIRONMENT
  - DEFINED AS AN ELECTROCHEMICAL REACTION
- A MATERIALS TENDENCY TO RETURN TO IT'S NATURAL STATE
  - IN THE CASE OF METAL - ORE

ENERGY CYCLE OF STEEL

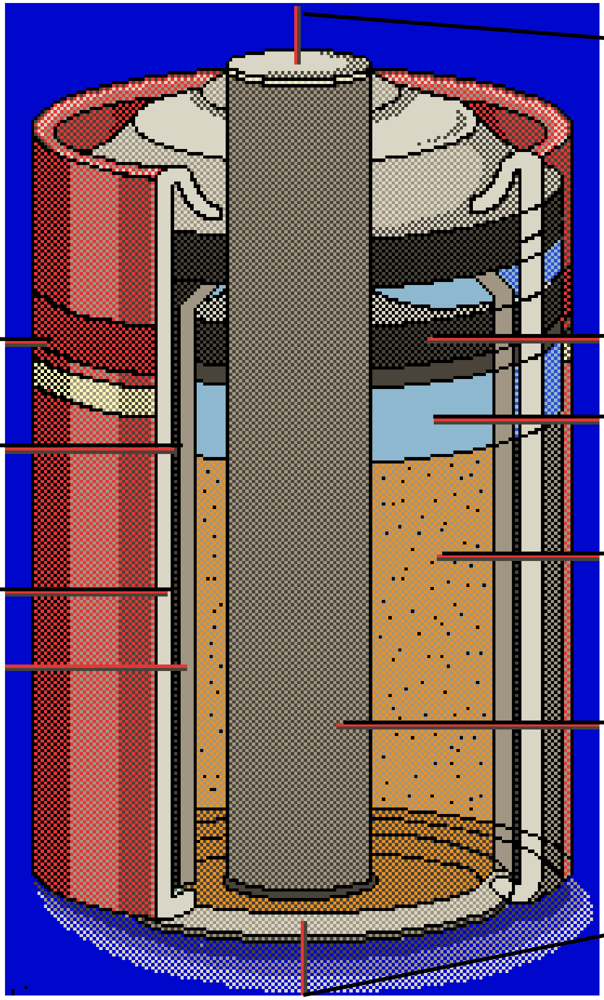


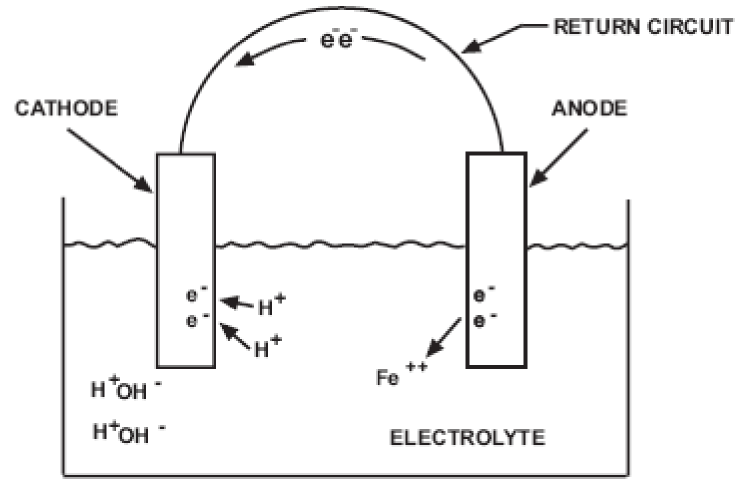
WHAT IS CORROSION?

- Corrosion cells are composed of the following four basic elements:

- Anode — The portion of a metal surface that is corroded from which current leaves the metal to enter the solution. The point where Oxidation occurs
- Cathode — The portion of a metal surface from which current leaves the electrolyte and returns to metal. The point where Reduction occurs
- Electrolyte — A solution containing Ions that is capable of conducting electricity
- Return Circuit — Metallic connection between the anode and cathode

GRAPHITE-ZINC BATTERY



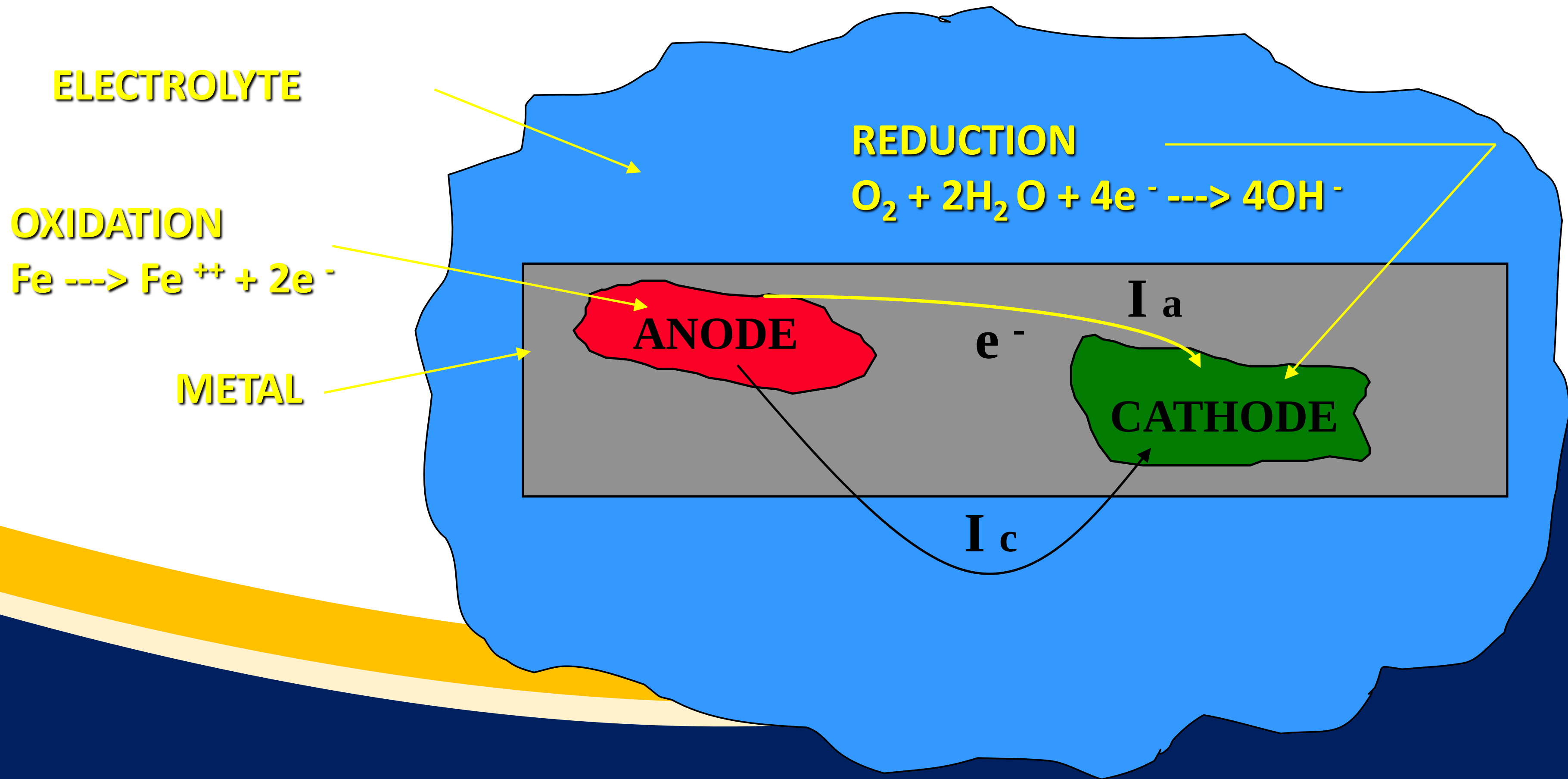


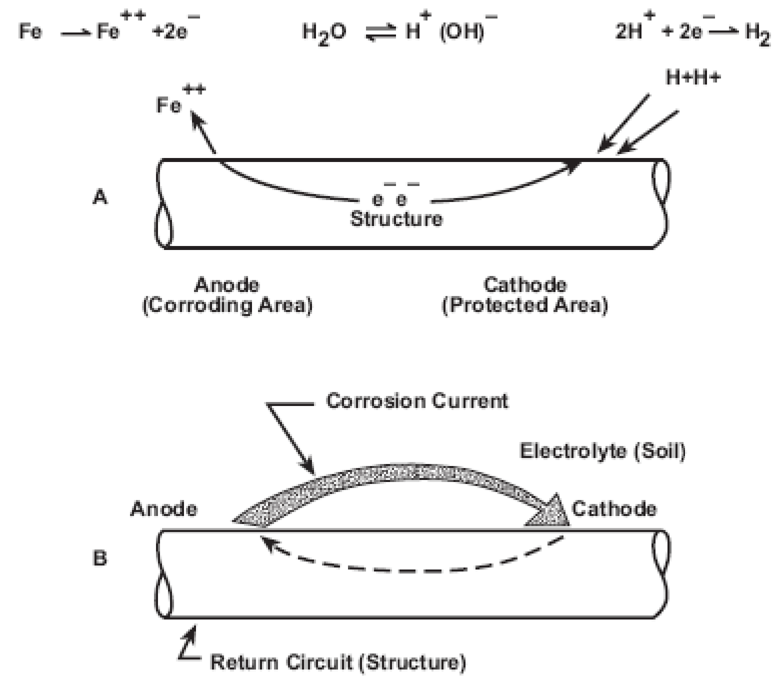
FUNDAMENTAL CORROSION CELL

FIGURE 2-1

THE CORROSION PROCESS

- ANODE
- CATHODE
- ELECTROLYTE
- METALLIC PATH





FUNDAMENTAL CORROSION CELL
AS IT APPLIES TO A PIPELINE
A Electrochemical cell
B Conventional current cell

FIGURE 2-2

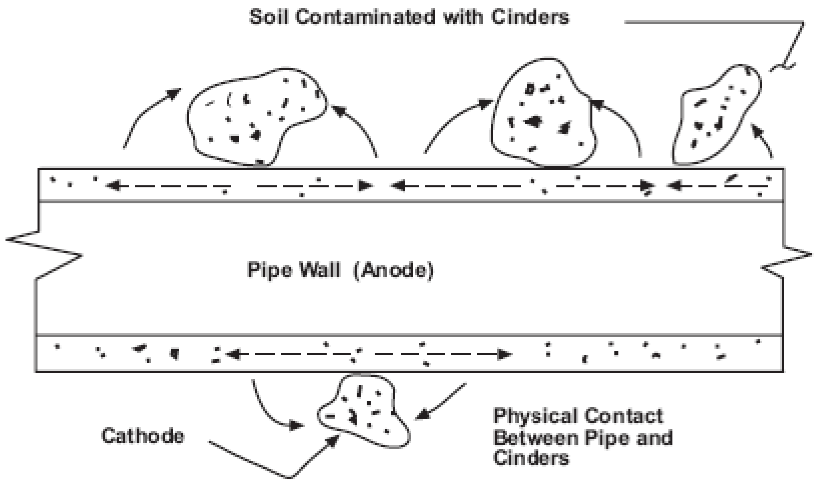
TWO TYPES OF UNDERGROUND CORROSION

- NATURAL CORROSION
- STRAY CURRENT CORROSION

NATURALLY OCCURING CORROSION

- DISSIMILAR METALS
- DISSIMILAR SURFACES
- DISSIMILAR SOILS
- DIFFERENTIAL AERATION
- CINDERS
- STRESS

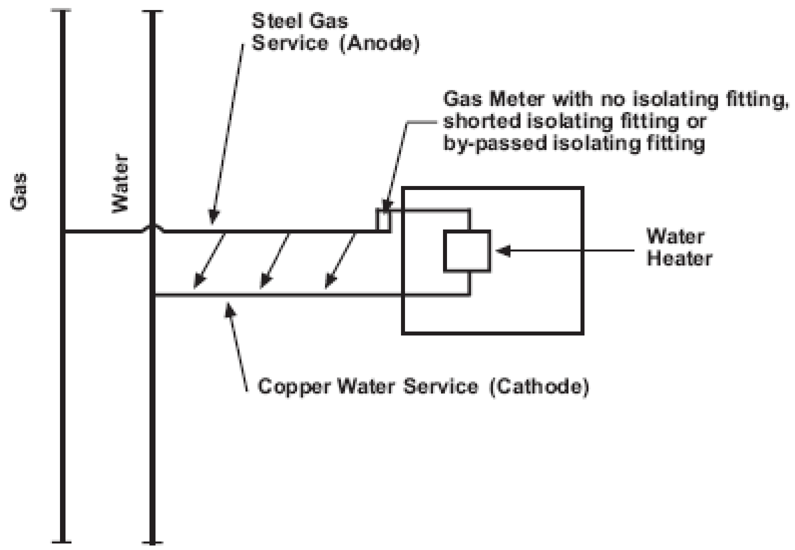
	Metal	Volts[1]
↑ Progressively more anodic (less noble) and more corrosive	Commercially pure magnesium	-1.75
	Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
	Zinc	-1.1
	Aluminum alloy (5% Zn)	-1.05
	Commercially pure aluminum	-0.8
	Mild steel (Clean and shiny)	-0.5 to -0.8
	Mild steel (rusted)	-0.2 to -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
↓ Progressively more cathodic (noble) and less corrosive	Carbon, graphite, coke	+0.3



CORROSION DUE TO CINDERS

FIGURE 2-3


36+50



DISSIMILAR METAL CORROSION
GAS AND WATER SERVICE LINES

FIGURE 2-4


JOHN DEERE

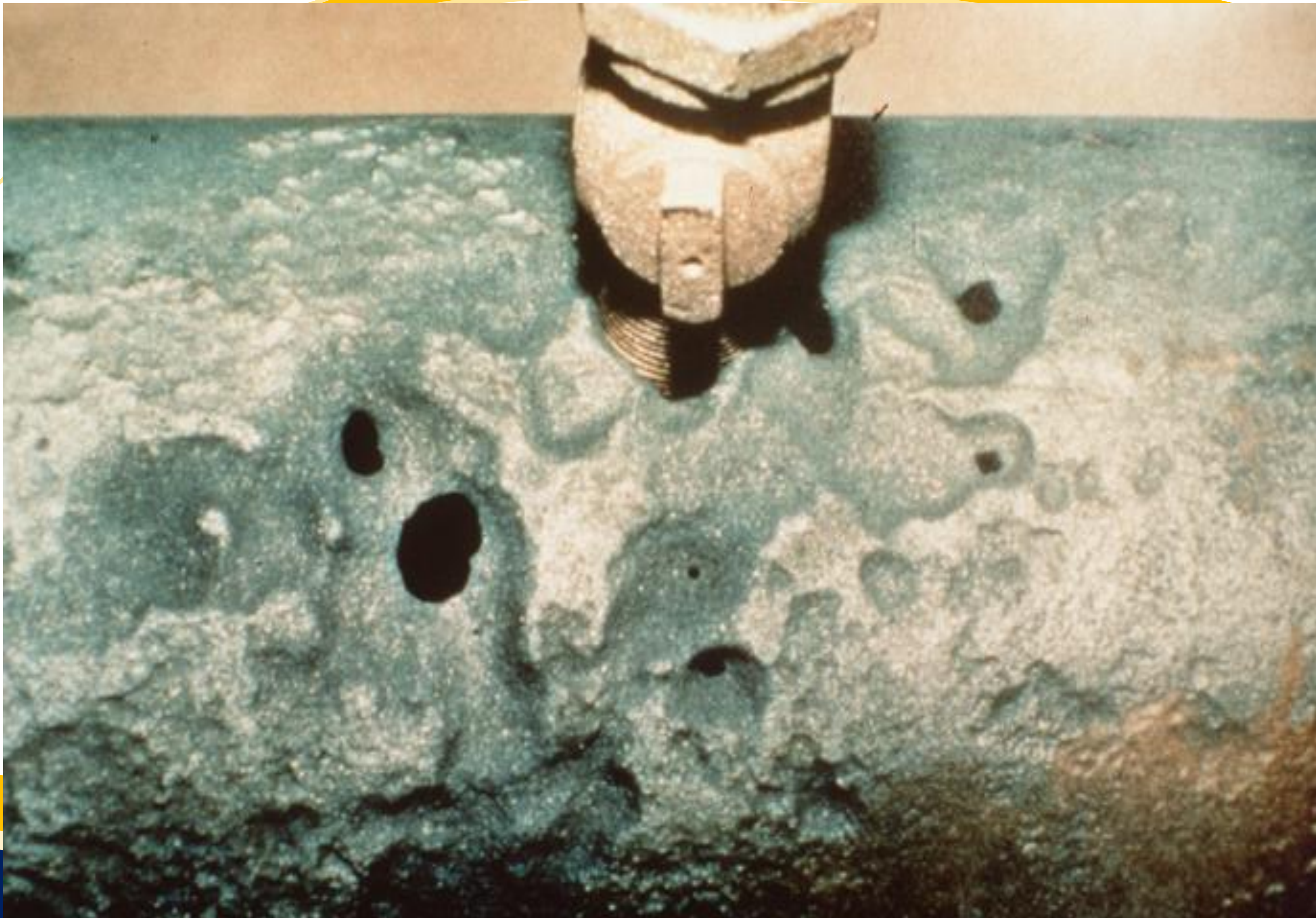


TABLE 2-1

PRACTICAL GALVANIC SERIES

↑ Progressively more anodic (less noble) and more corrosive

Metal	Volts(1)
Commercially pure magnesium	-1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% Zn)	-1.05
Commercially pure aluminum	-0.8
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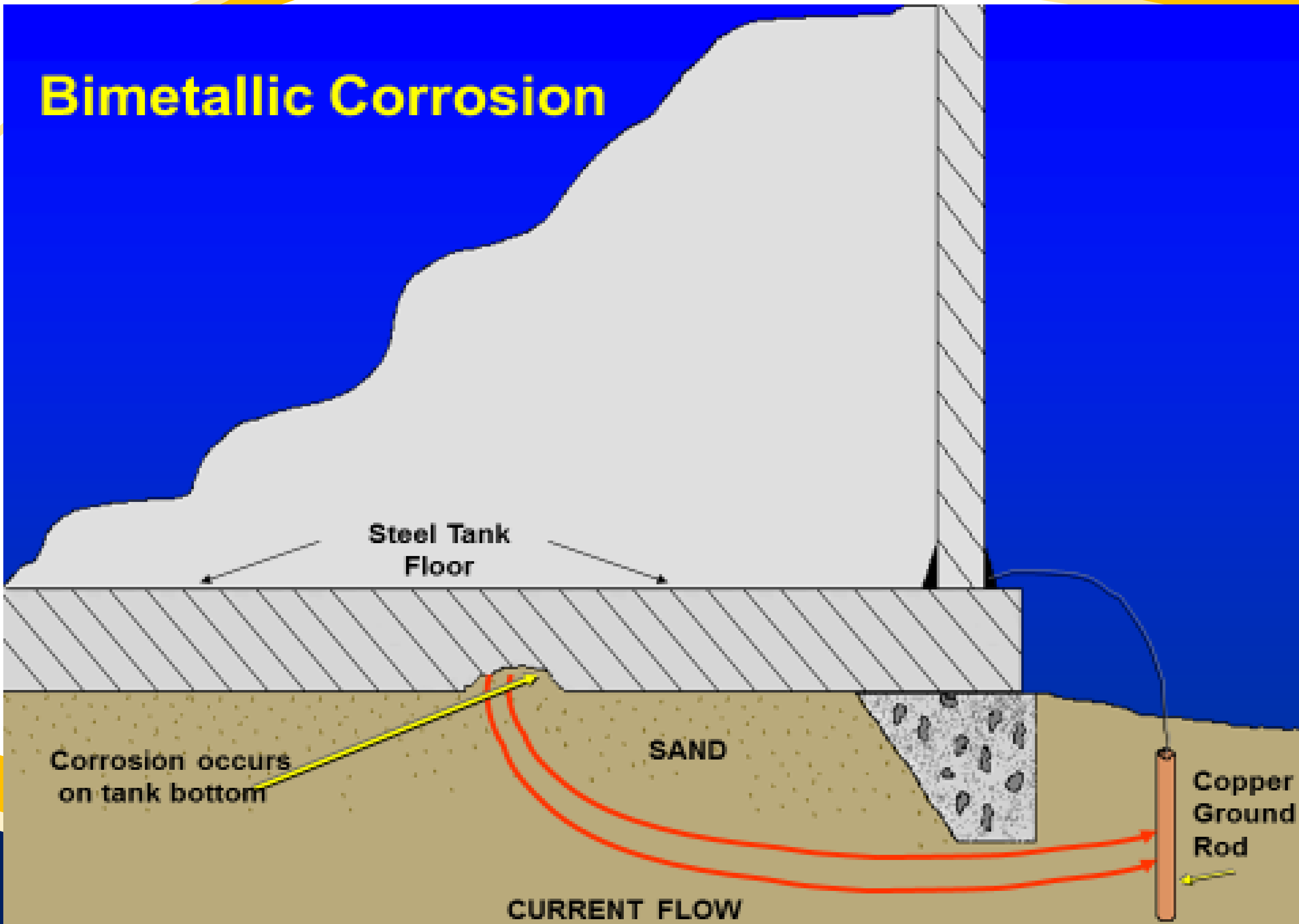
Mild steel in concrete	-0.2
Copper, brass, bronze	-0.2
High silicon cast iron	-0.2
Mill scale on steel	-0.2
Carbon, graphite, coke	+0.3

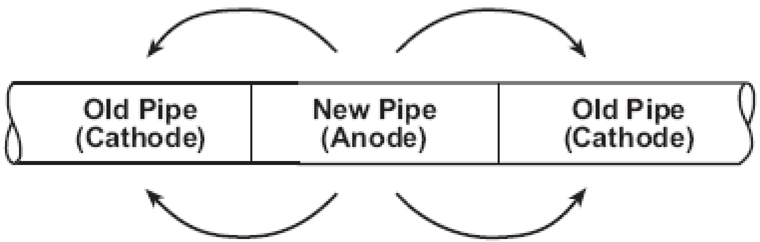
↓ Progressively more cathodic (noble) and less corrosive

(1) Typical potentials measured between metal (when immersed in neutral soils or waters) and a copper-copper sulfate reference cell contacting the adjacent soil or water.

Bimetallic Corrosion



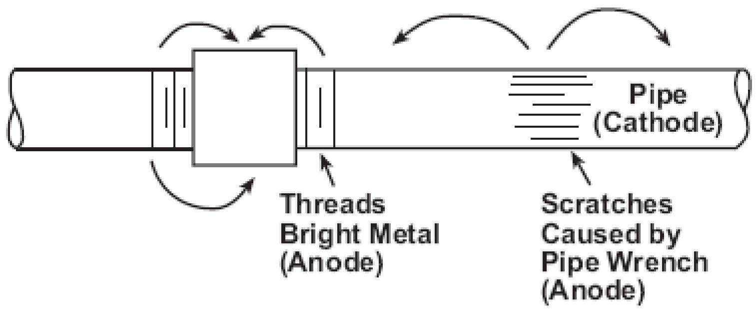
DISSIMILAR SURFACES



NEW-OLD PIPE CELL

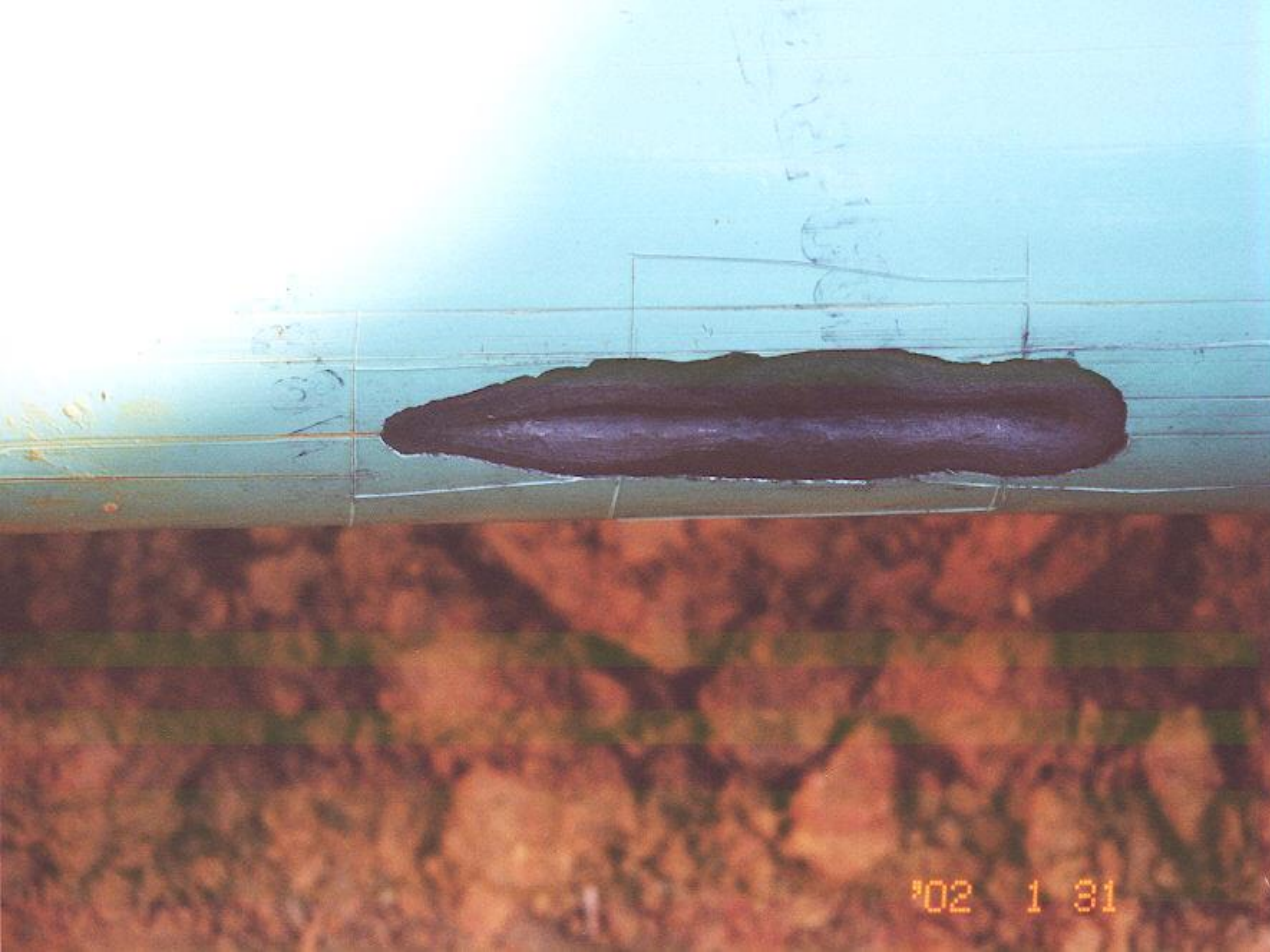
FIGURE 2-5

DISSIMILAR SURFACES



CORROSION CAUSED BY
DISSIMILARITY OF SURFACE CONDITIONS

FIGURE 2-6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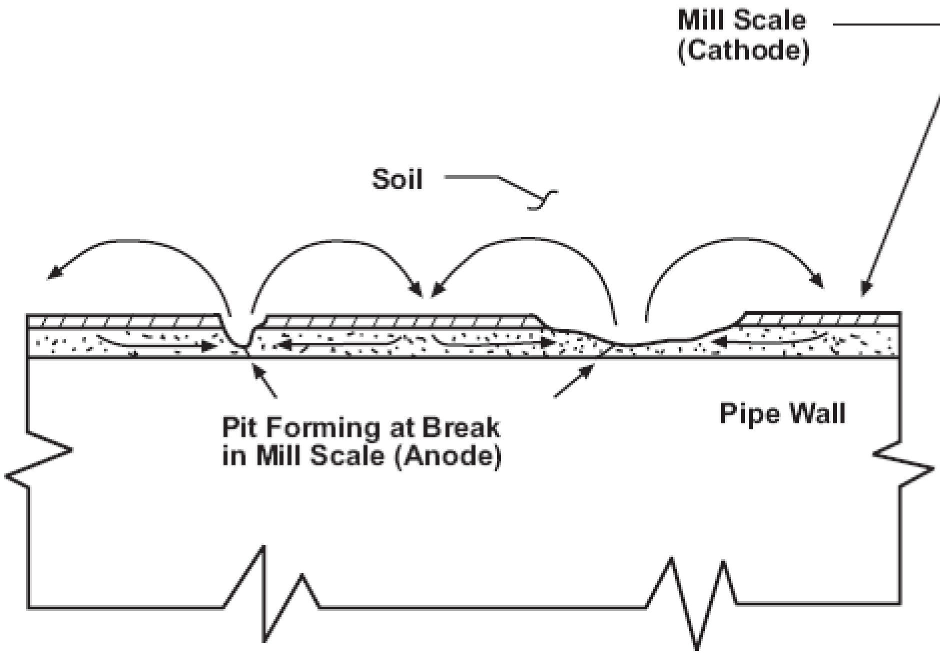
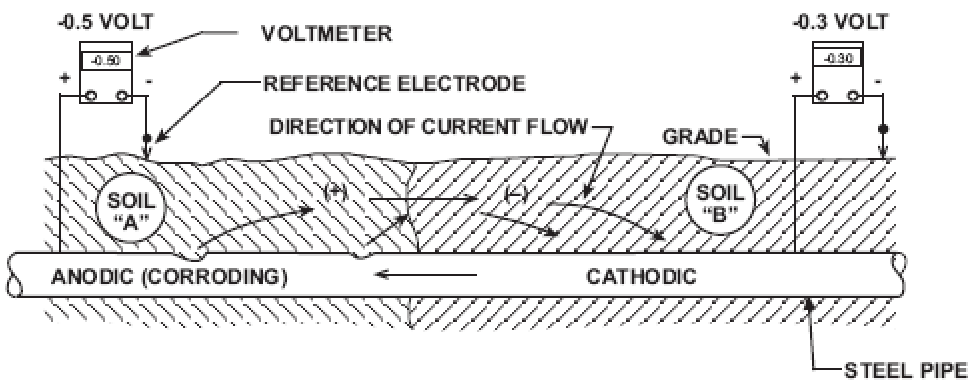


PITTING DUE TO MILL SCALE

FIGURE 2-7

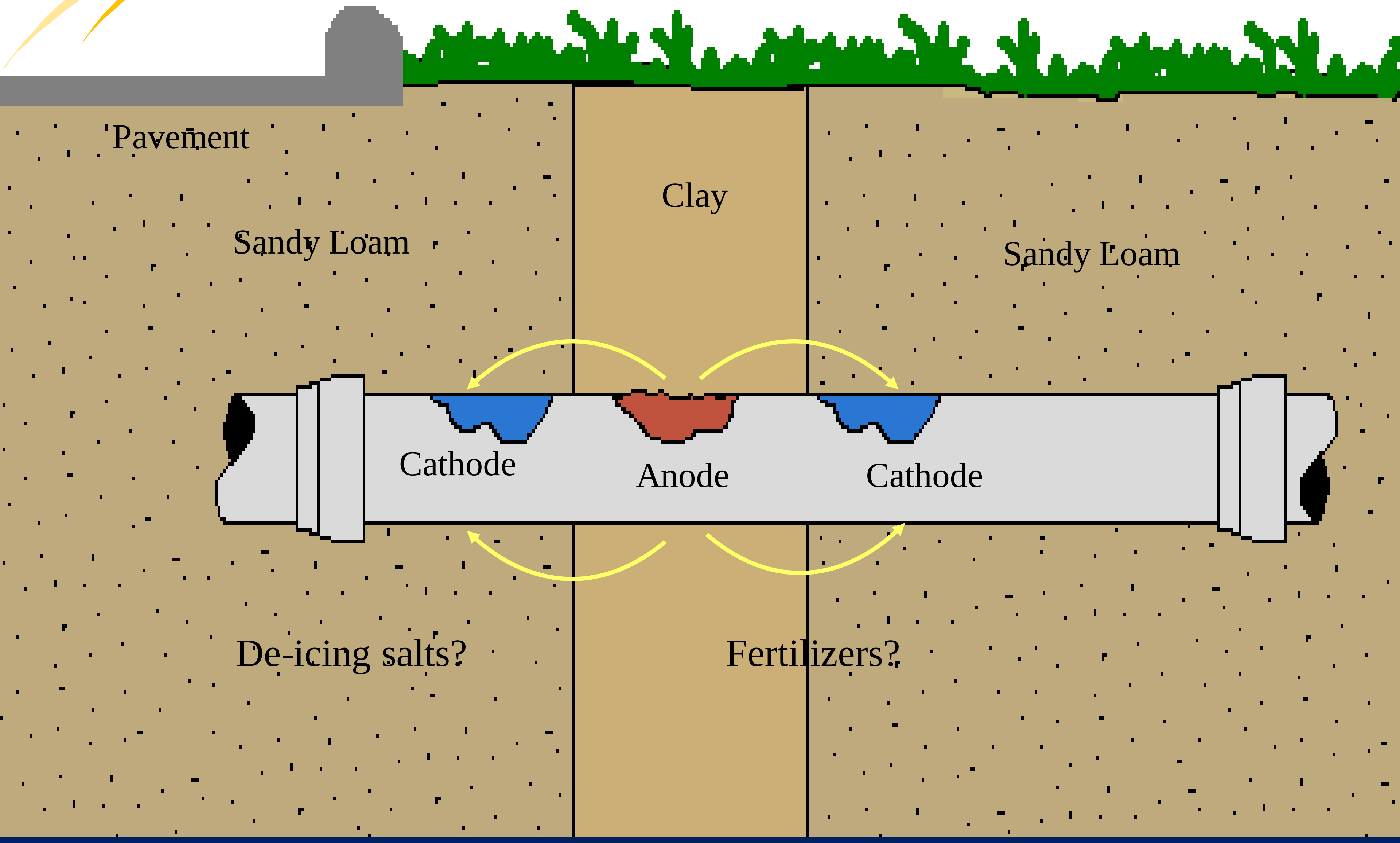
DISSIMILAR SOILS



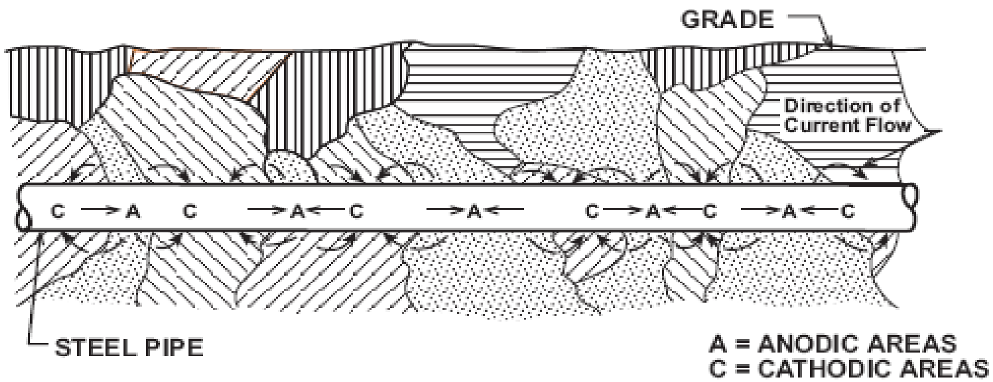
DISSIMILAR SOILS AS SOURCE
OF CORROSION CELL POTENTIAL

FIGURE 2-8

DISSIMILAR SOILS



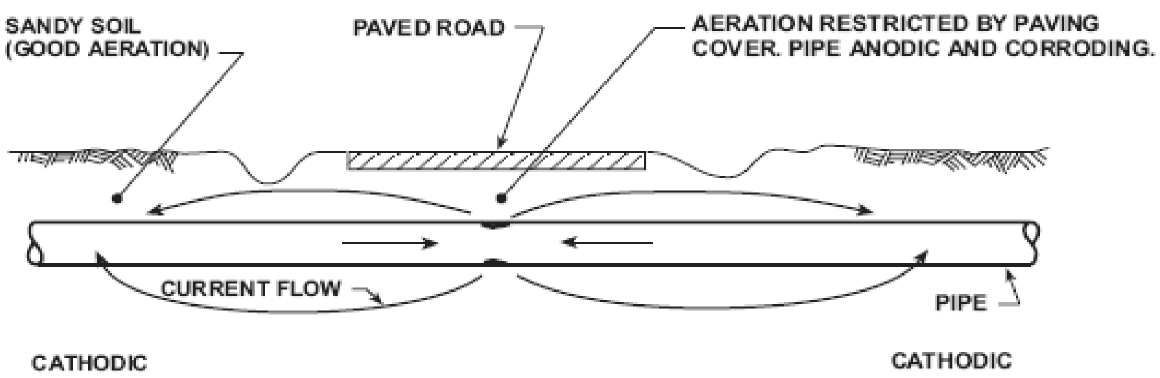
DISSIMILAR SOILS



MIXTURE OF DISSIMILAR SOILS
AS SOURCE OF CORROSION CELL POTENTIALS

FIGURE 2-9

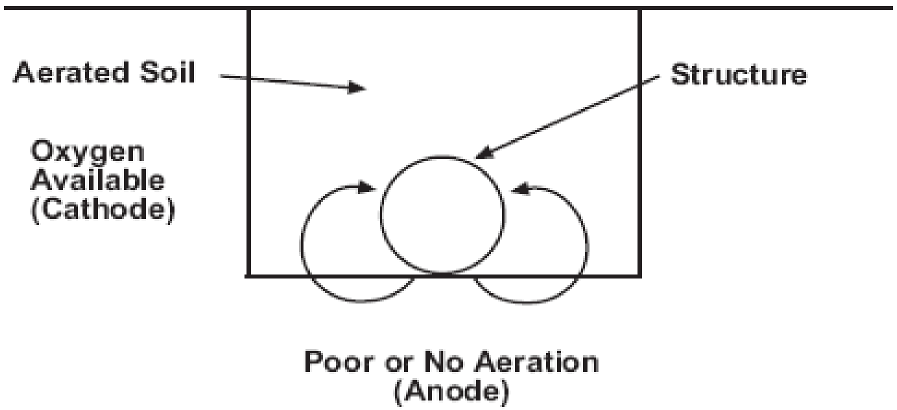
DIFFERENTAL AERATION



DIFFERENTIAL AERATION AS A
SOURCE OF CORROSION CELL POTENTIAL

FIGURE 2-10

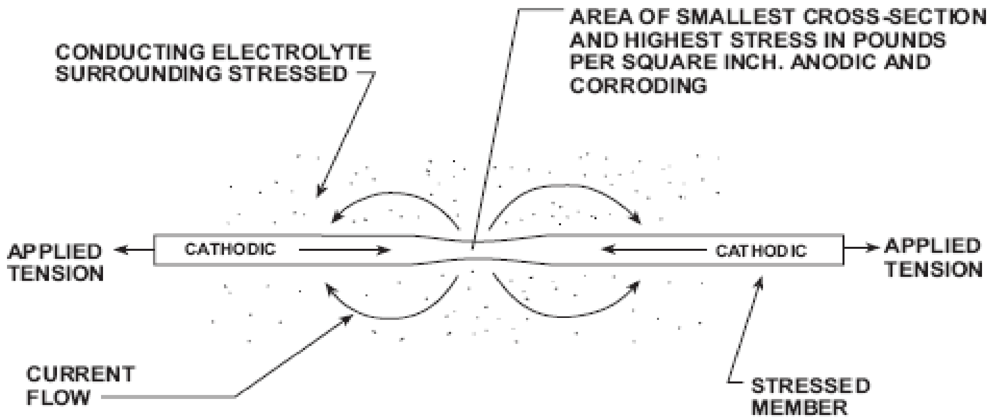
DIFFERENTIAL AERATION



CORROSION CAUSED BY
DIFFERENTIAL AERATION OF SOIL

FIGURE 2-11

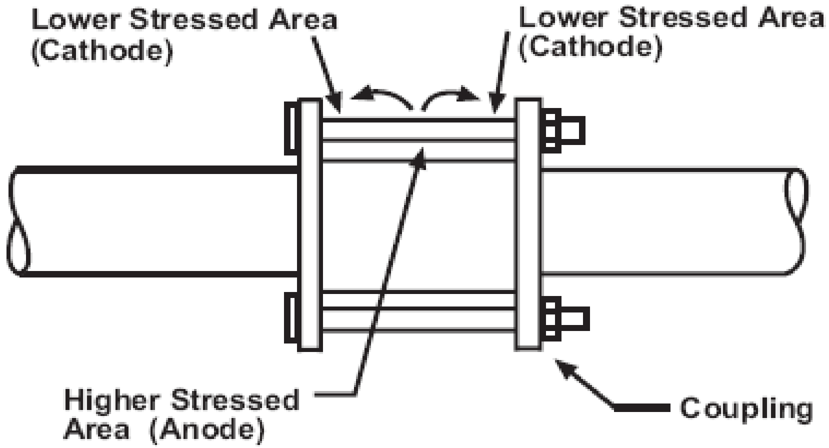
STRESS CORROSION



DIFFERENTIAL STRESS AS A SOURCE OF CORROSION CELL POTENTIAL

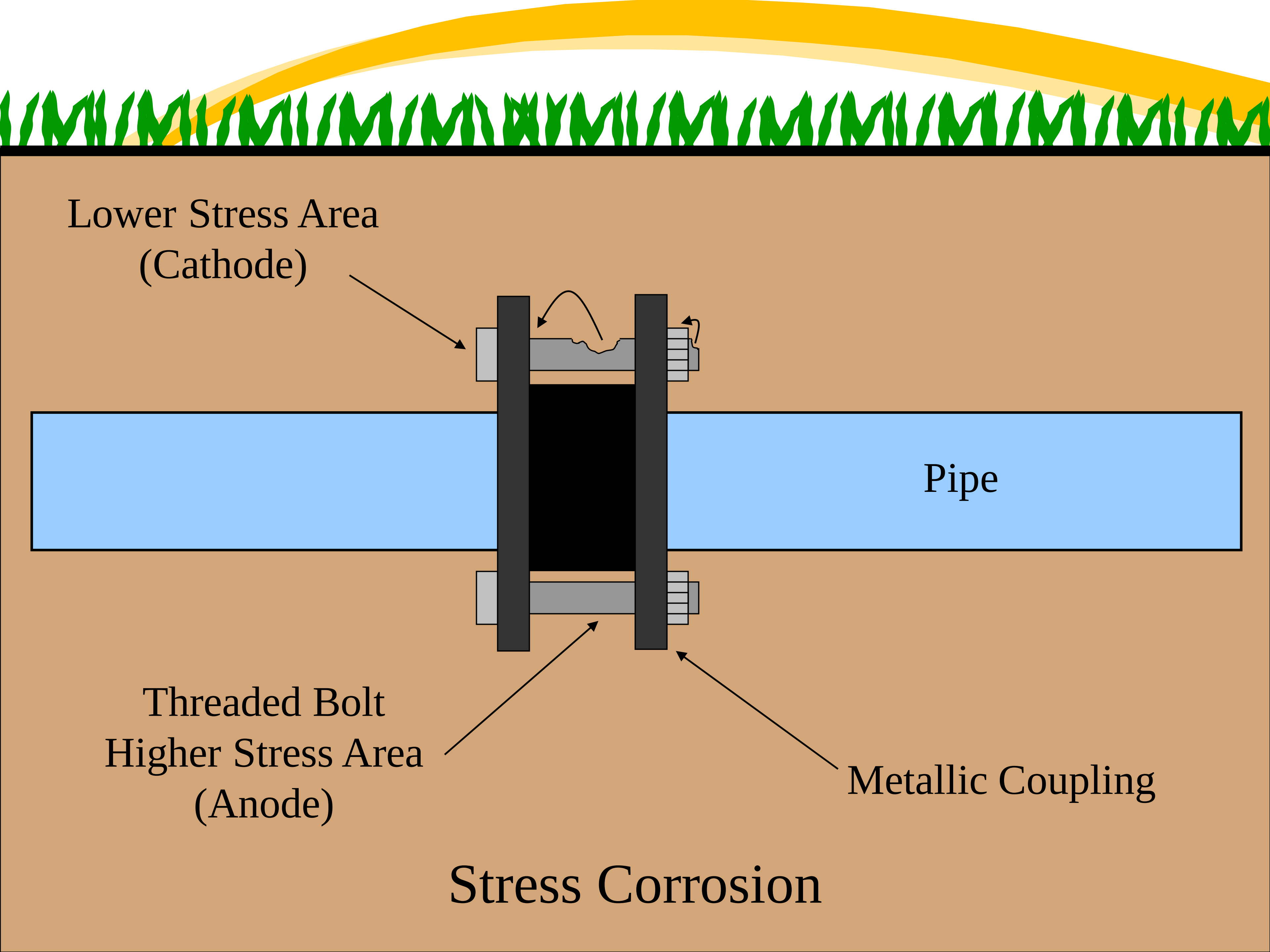
FIGURE 2-12

STRESS CORROSION



STRESS CORROSION

FIGURE 2-13



Lower Stress Area
(Cathode)
Pipe
Threaded Bolt
Higher Stress Area
(Anode)
Metallic Coupling
Stress Corrosion

CAST IRON GRAPHITIZATION

- WHY??????
  - MUCH MORE CARBON IN CAST IRON (3-4%) THAN IN STEEL(1%)

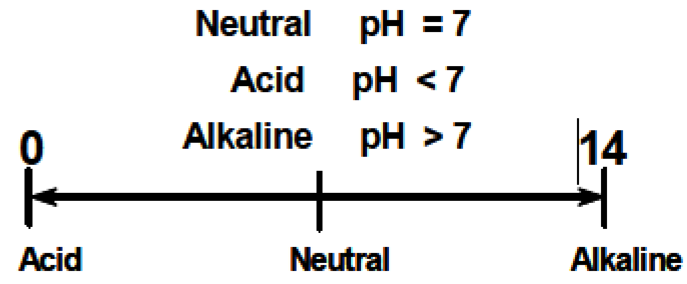
- RETAINS THE ORIGINAL STRUTURE BUT EASILY FLAKES OFF

MICROBIOLOGICALLY INFLUENCED CORROSION

- ANAEROBIC BACTERIA
- SULFATE REDUCING TYPE
- CONSUMES HYDROGEN

pH LEVELS

- pH Scale: 0-14
- Rate of corrosion increases – below 4
- Rate of corrosion independent – 4-8
- Rate of corrosion decreased – above 8

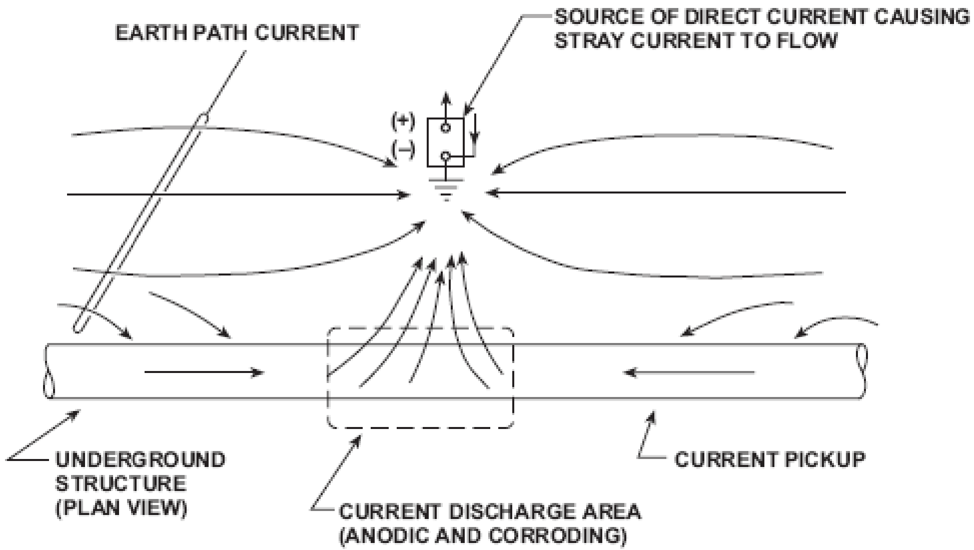


AMPHOTERIC METALS

- SENSITIVE TO STRONG ALKALINE CONDITIONS (HIGHER RATE OF CORROSION)
- PART ONE AND PART THE OTHER
- LEAD, TIN, AND ALUMINUM
- STRAY CURRENT CONDITIONS

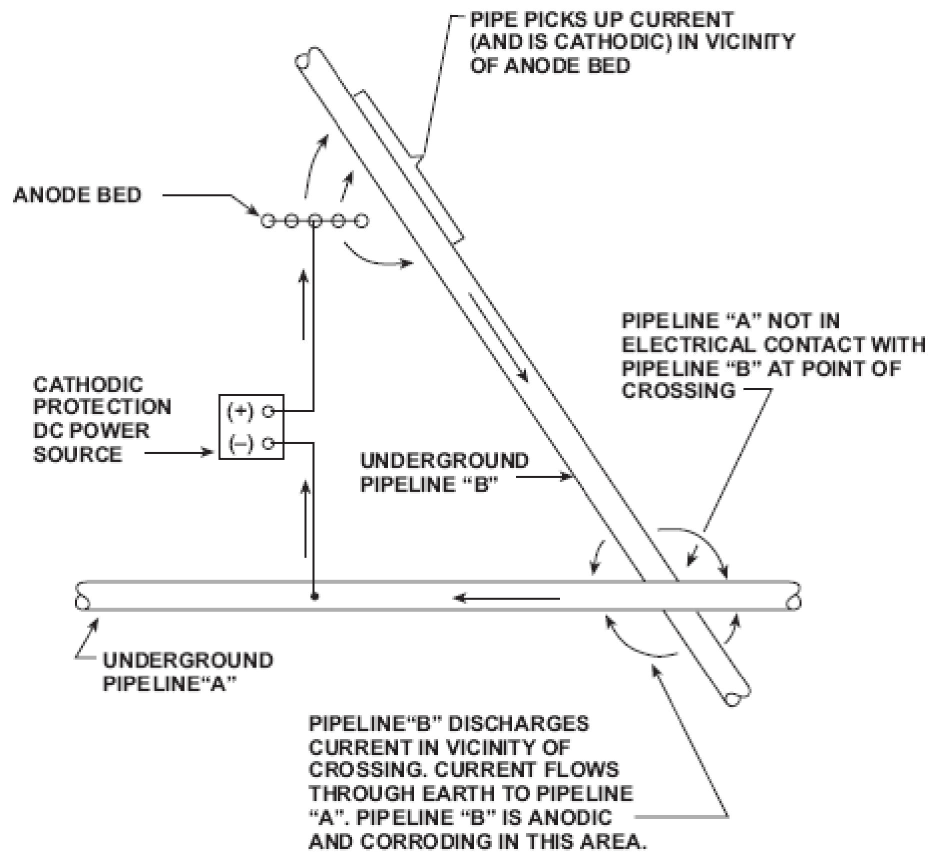
STRAY CURRENT CORROSION

- DYNAMIC
  - ELECTRIFIED RAILROADS
  - TRANSIT SYSTEMS
  - MINE RAILROADS
  - WELDING OPERATIONS
- STATIC
  - IMPRESSED CURRENT CATHODIC PROTECTION



PARALLEL EARTH PATHS
CAUSING STRAY CURRENT CORROSION

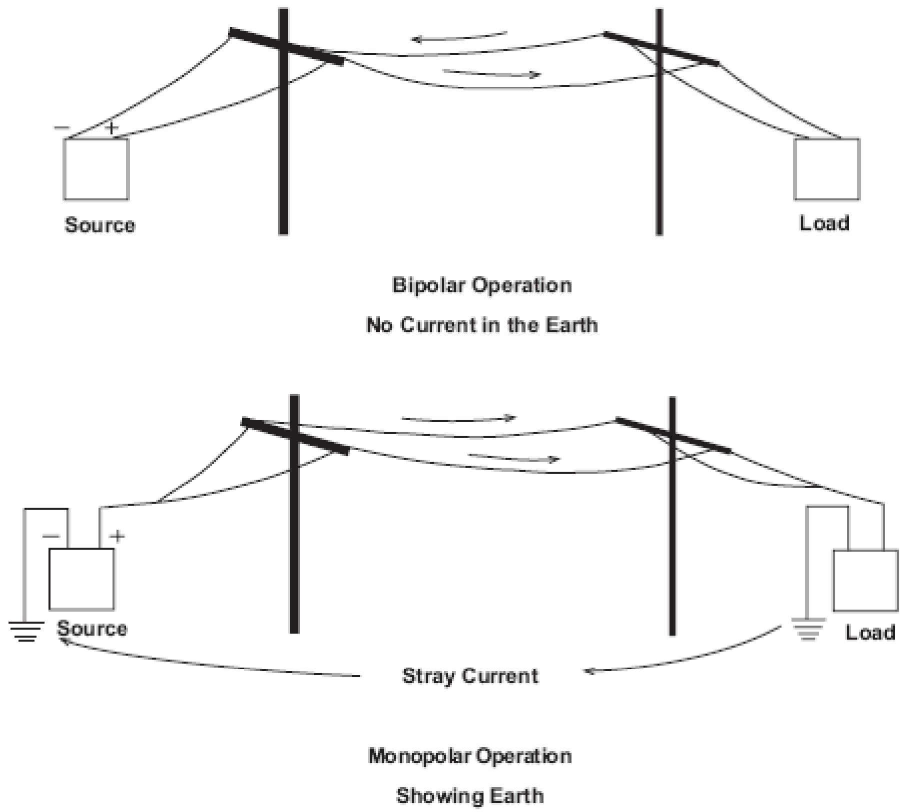
FIGURE 2-14



STRAY CURRENT CORROSION
FROM CATHODIC PROTECTION SYSTEM

FIGURE 2-15


WARNING
GAS
WARNING
GAS



HIGH VOLTAGE DC TRANSMISSION LINE

FIGURE 2-16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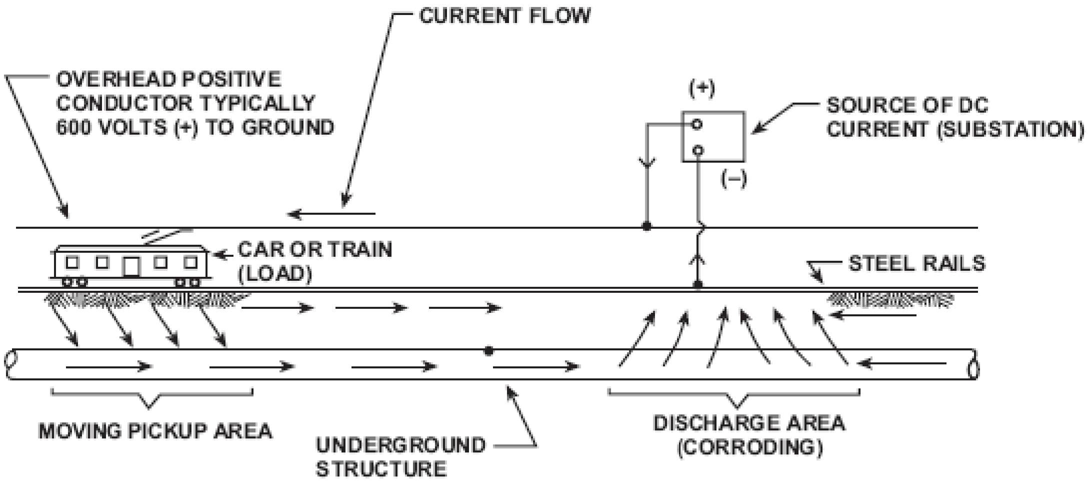
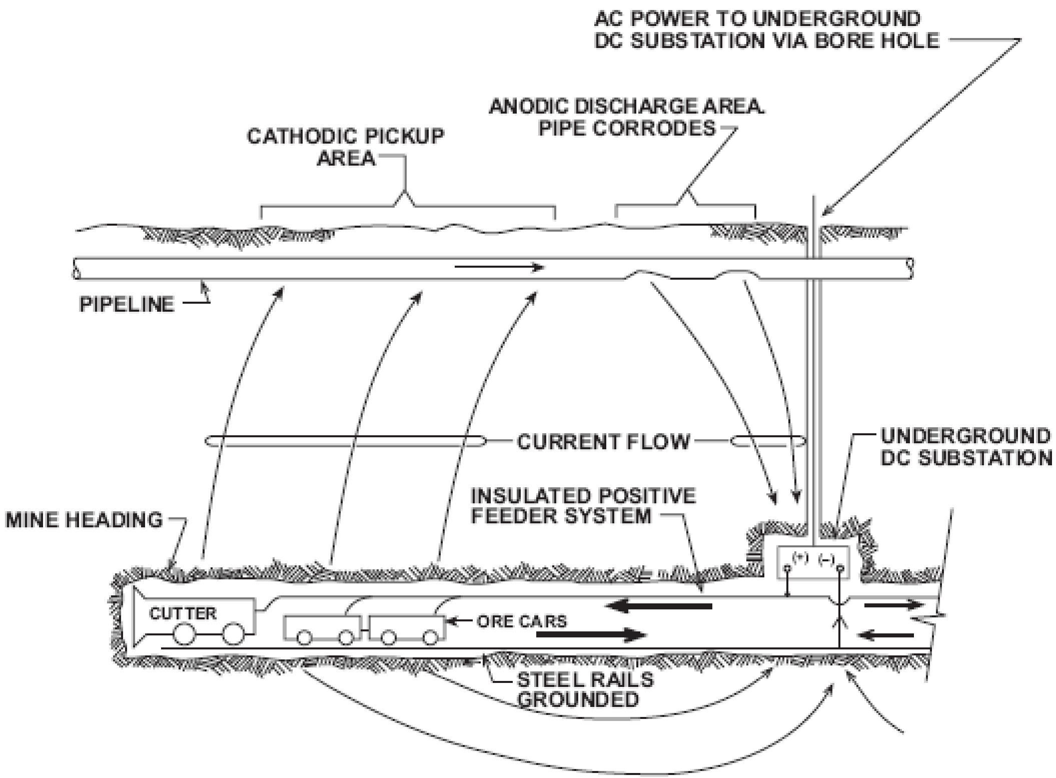


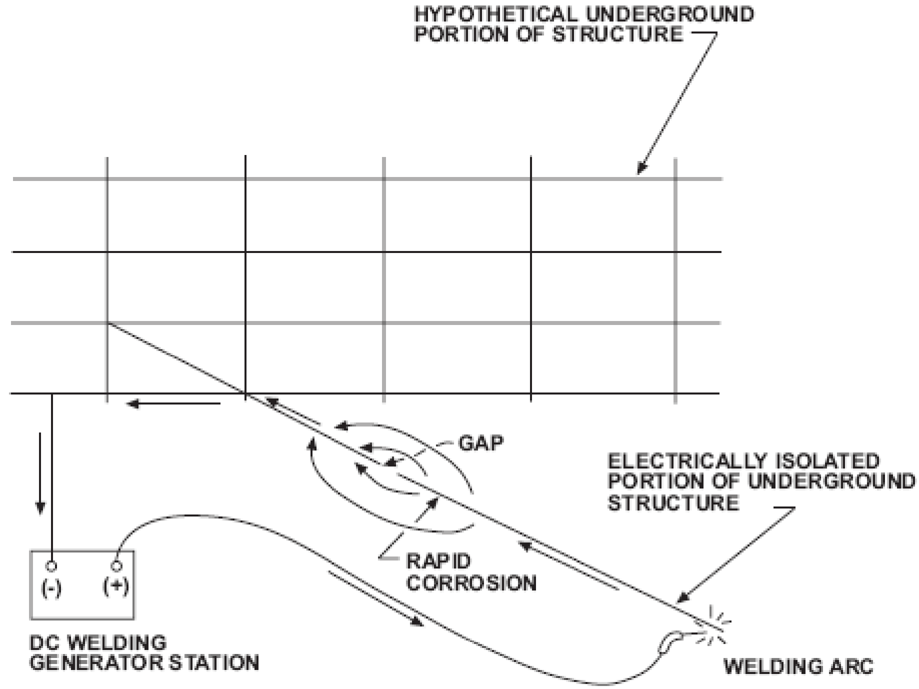
DC TRANSIT SYSTEM AS A SOURCE OF
STRAY CURRENT CORROSION

FIGURE 2-17



CORROSION BY STRAY CURRENT
FROM DC MINING OPERATIONS

FIGURE 2-18



CORROSION BY STRAY CURRENT
FROM DC WELDING OPERATIONS

FIGURE 2-19

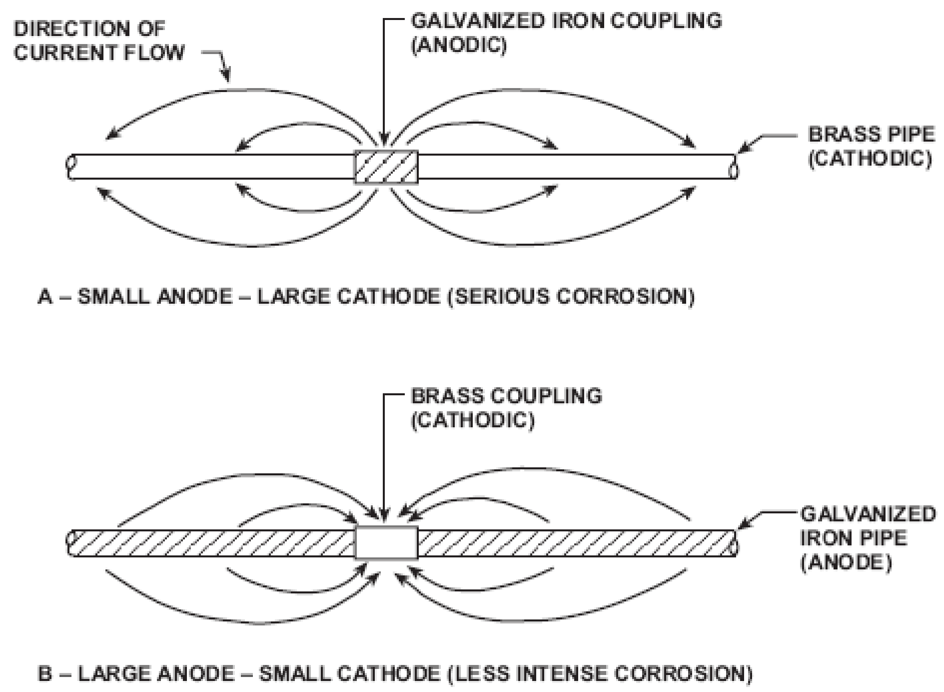
RATE OF CORROSION

Directly proportional to the amount of current leaving the anodic metal

$$I = E/R$$

Where:

- I = Current in Amperes
- E = Voltage in Volts
- R = Resistance in Ohms



ANODE-CATHODE SIZE RELATIONSHIP

FIGURE 2-20

TABLE 2-2

CONSUMPTION RATES OF TYPICAL METALS

Metal	Electrochemical Equivalent (Grams per coulomb)	Consumption Rate (Pounds per Ampere-year)	Volume of Metal Consumed (Cubic inches per Ampere-year)
Carbon* (C^{+++})**	0.4149×10^{-4}	2.89	36.99
Aluminum (Al^{+++})	0.9316×10^{-4}	6.48	69.99
Magnesium (Mg^{++})	1.2600×10^{-4}	8.76	141.47
Iron (Fe^{++})	2.8938×10^{-4}	20.12	70.81
Nickel (Ni^{++})	3.0409×10^{-4}	21.15	67.06
Copper (Cu^{++})	6.5875×10^{-4}	45.81	142.89
Zinc (Zn^{++})	3.3875×10^{-4}	23.56	90.87
Tin (Sn^{++})	6.1502×10^{-4}	42.77	162.43
Lead (Pb^{++})	10.736×10^{-4}	74.65	181.68

* Carbon is not strictly classified as a metal but as a metalloid -- but subject to consumption as a metal.

** Each metal is followed by its chemical symbol. The number of (+) signs following the symbol indicates the valence (a chemical term) for a typical anode reaction. The electrochemical equivalents are calculated on the valence shown. Other valences may apply under certain conditions for some metals.

FARADAY'S LAW (RATE OF CORROSION)

$$W = K \times I \times T$$

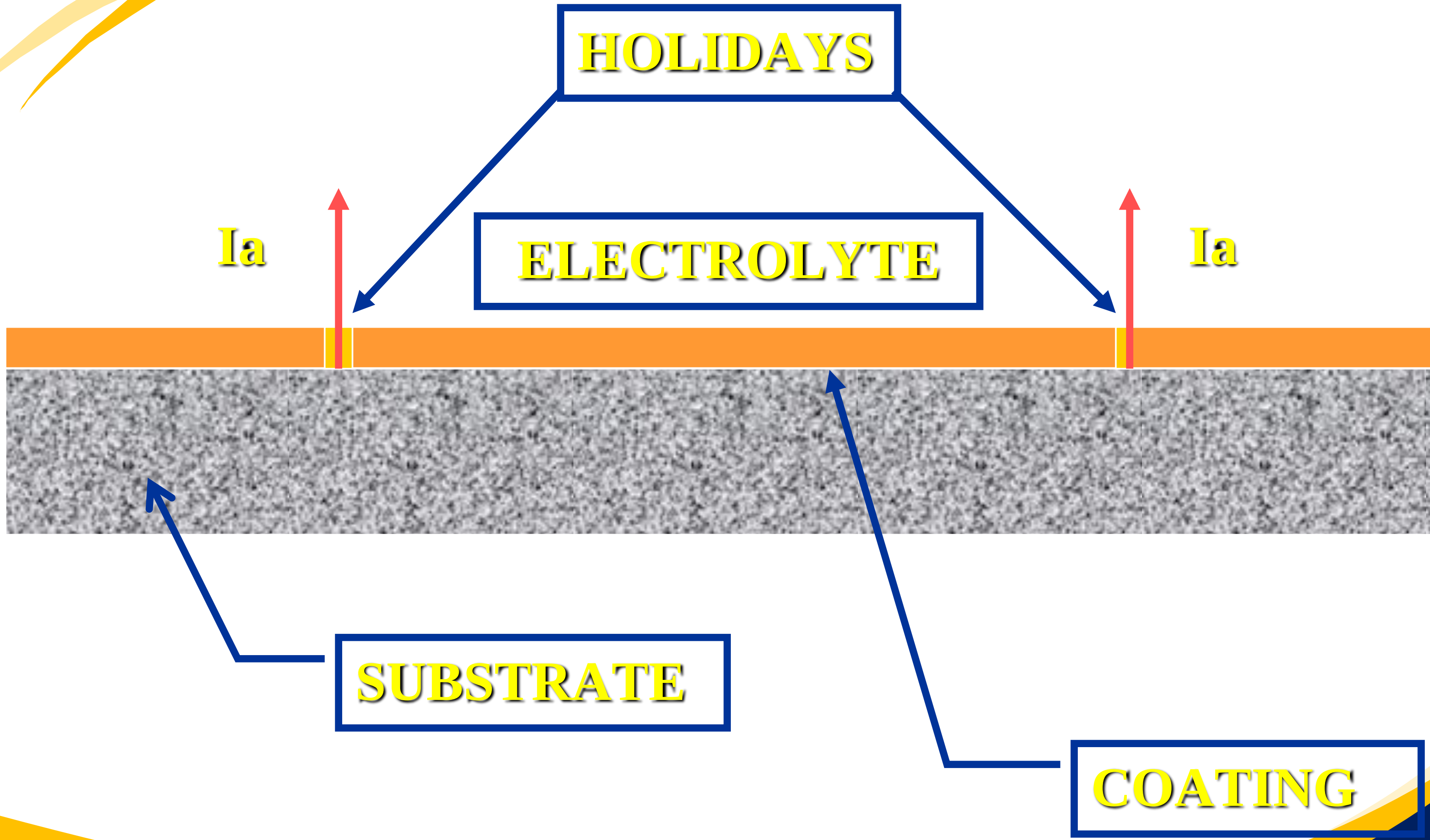
Where:

W = Weight Loss in One Year

K = Electrochemical Equivalent in Pounds Per Ampere Per Year

I = Corrosion Current in Amperes

T = Time in Years


HOLIDAYS
Ia
ELECTROLYTE
Ia
SUBSTRATE
COATING

QUESTIONS ?