Case Study
Corrosion Experiences using Hot Dip Galvanized Steel on South African Mines

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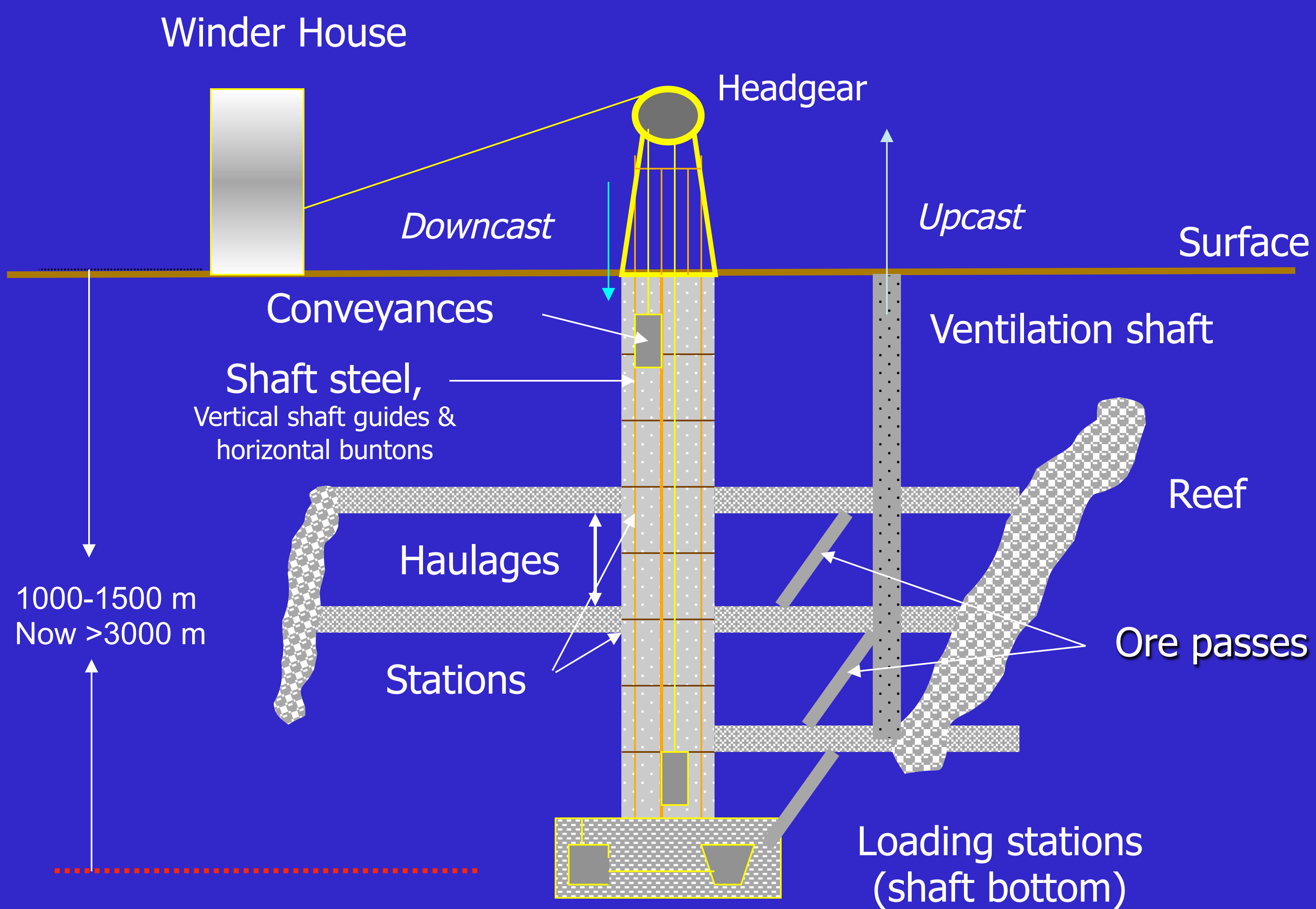
Presentation Over View

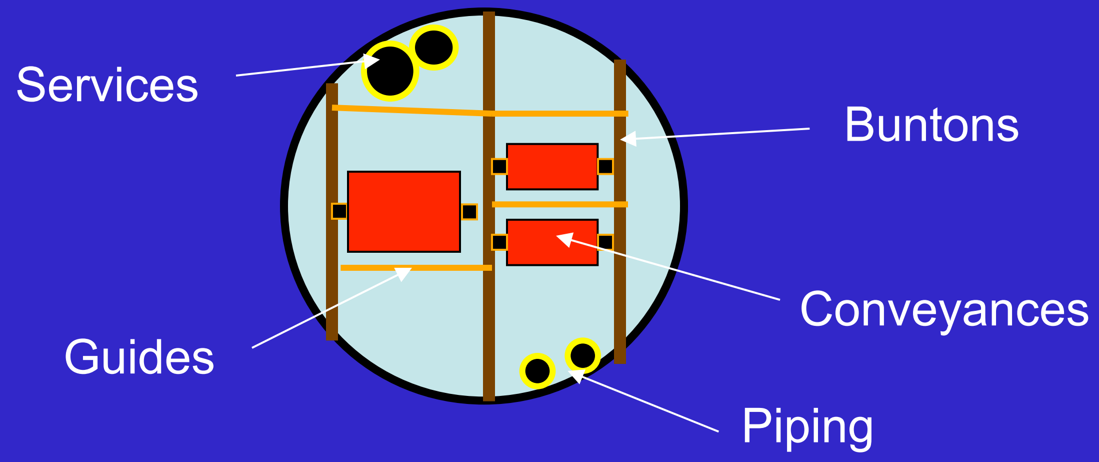
- Corrosivity of a Typical Vertical Mine Shaft
- How does Zinc Protect?
- Corrosion Investigation during the Design Stages for a new mine
- Follow up Shaft Inspections
- Current Structural Integrity Concerns
- **Erosion Corrosion** of Coated Steel
- Proposed Corrective Actions
- Conclusion and Questions

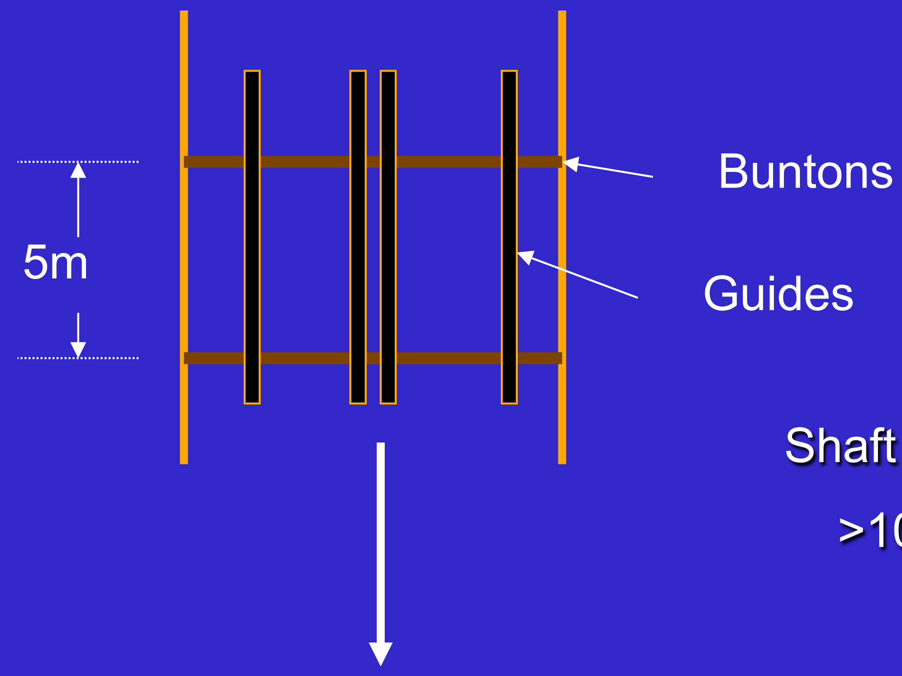
Data from various mines have been used in compiling this presentation

Vertical Mine Shafts



Shaft Steelwork



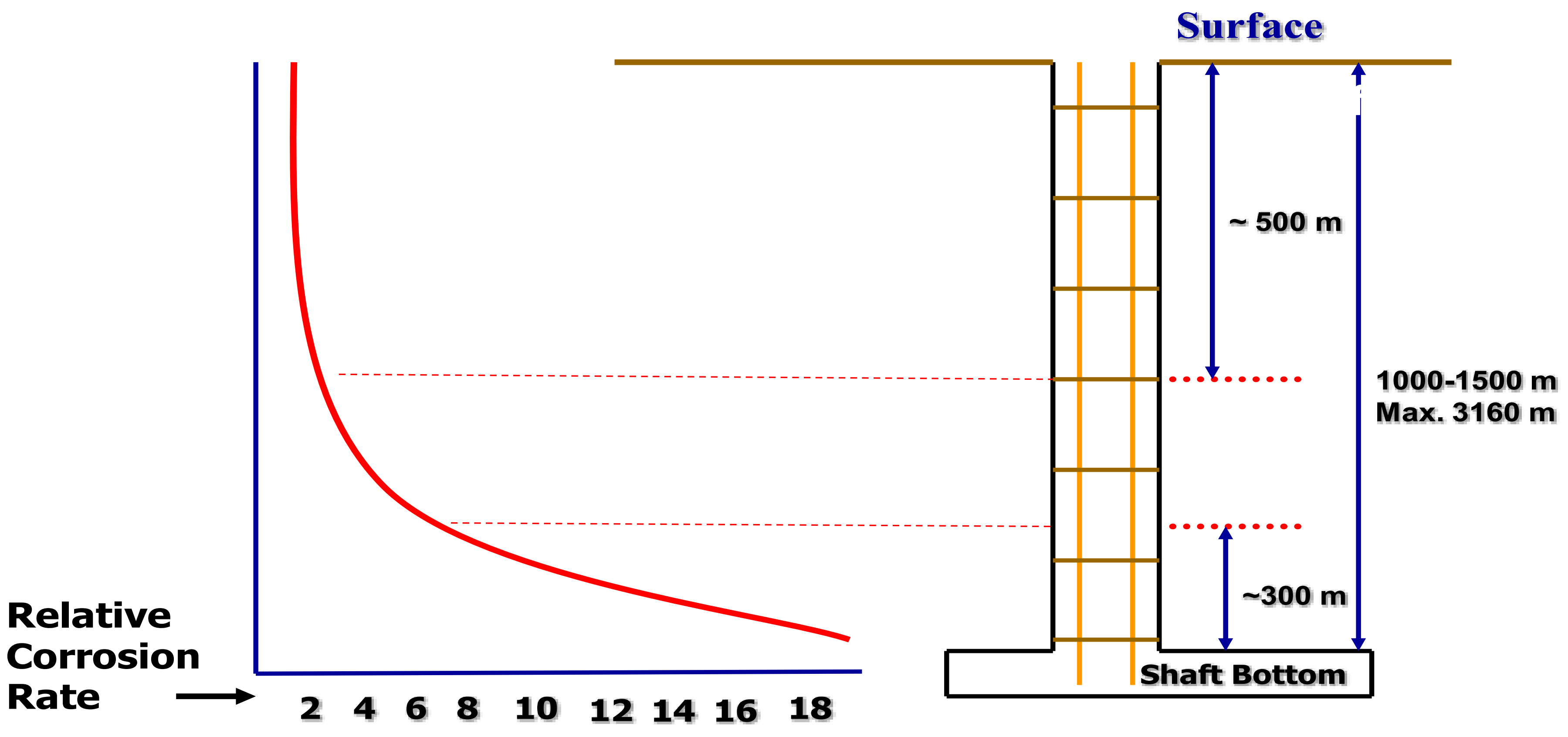


Shaft Diameters

>10 meters

Typical Cross Section of a Deep Level Mine Shaft

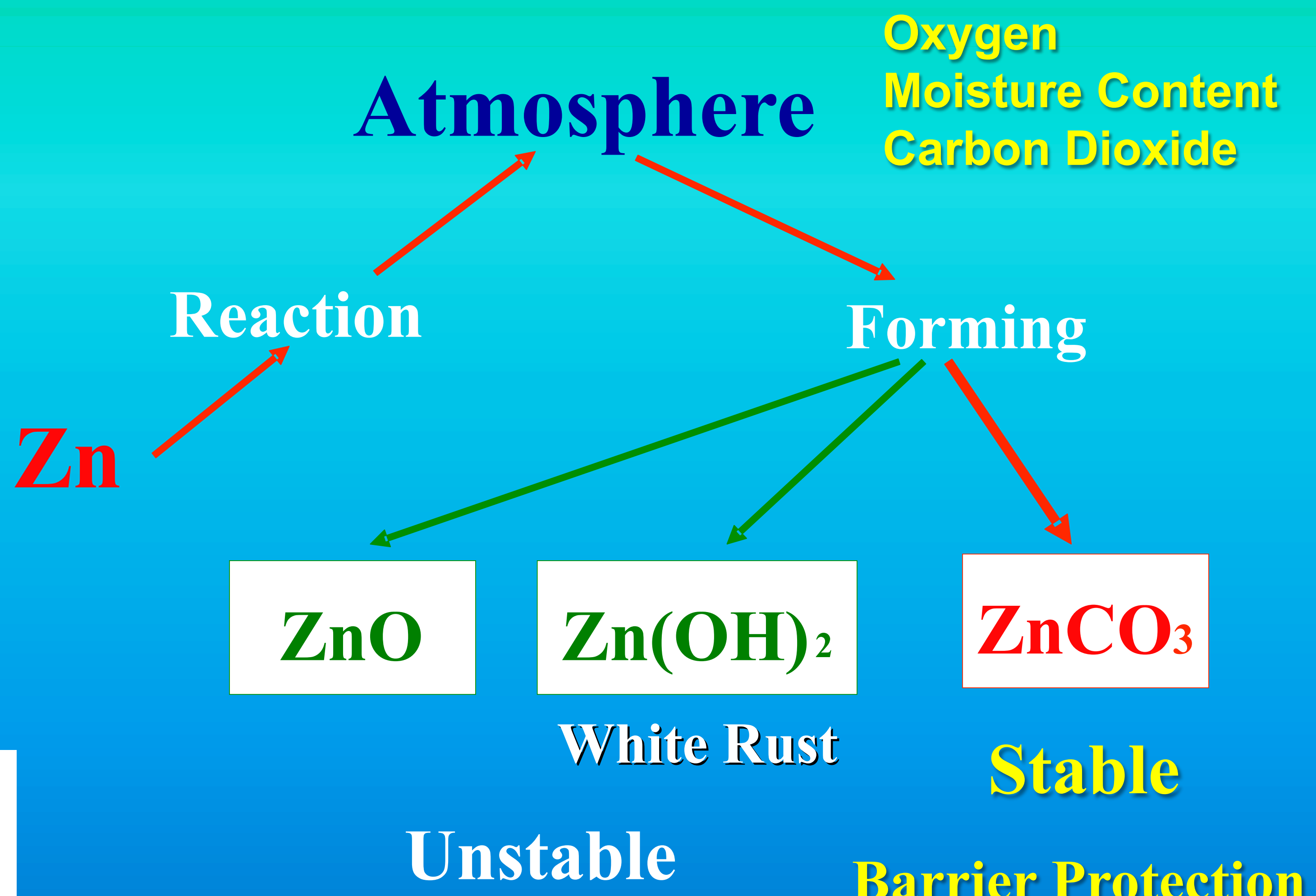
Corrosion Profile: Vertical Shafts



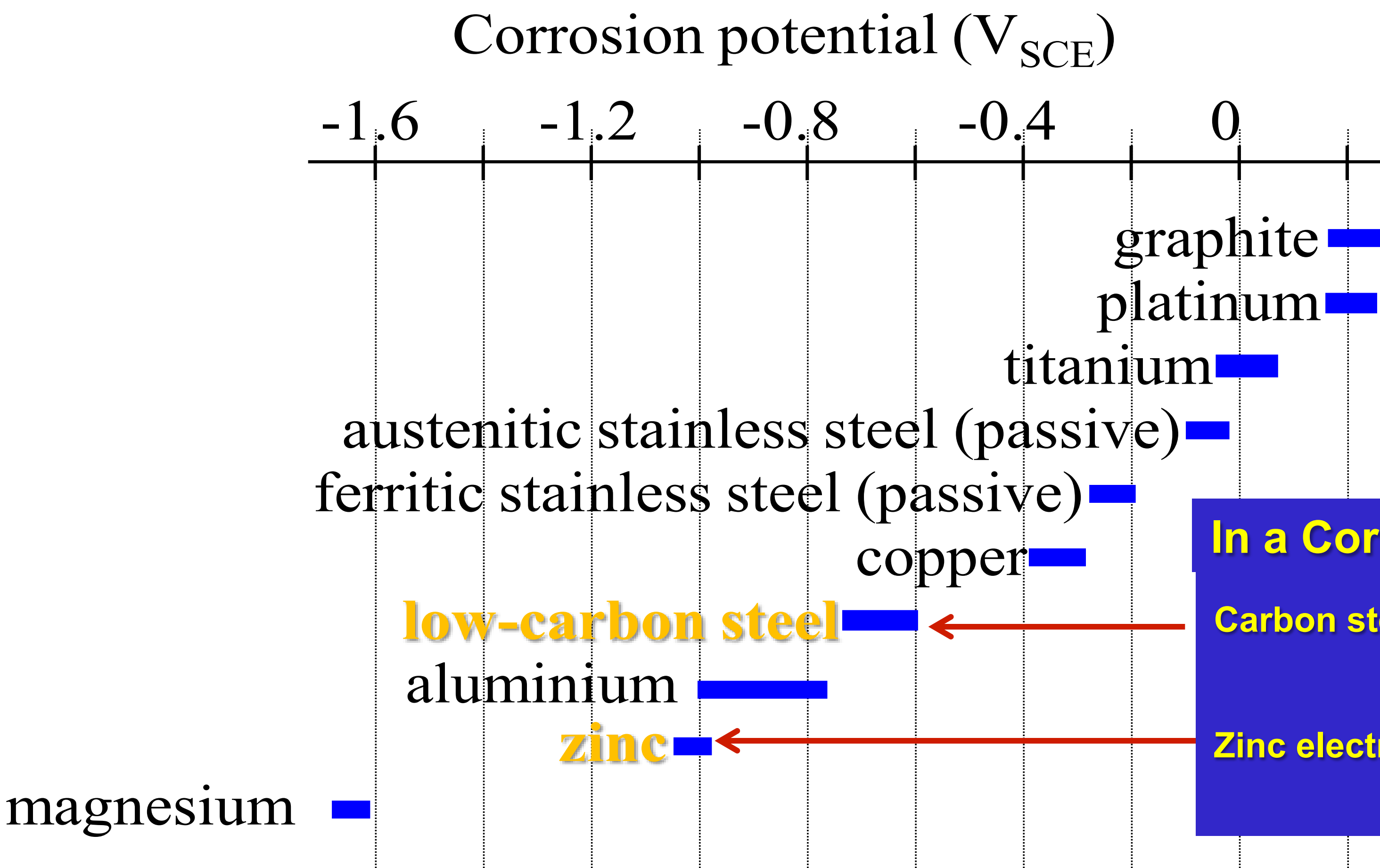
Typical Corrosive Conditions in Mine Shafts

- **Corrosive Waters**
- **Humidity and Elevated Temperature**
- **Contaminated Atmospheres**
- **Corrosive Ores and Dusts**
- **Abrasion i.e. “Erosion Corrosion”**
- **Mechanical “Handling” Damage**
- **High Degree of Variability of Environmental Conditions**

Simplified Diagram of how Zinc Reacts in an Atmosphere



Galvanic series in seawater



In a Corrosion Cell

Carbon steel = Cathode

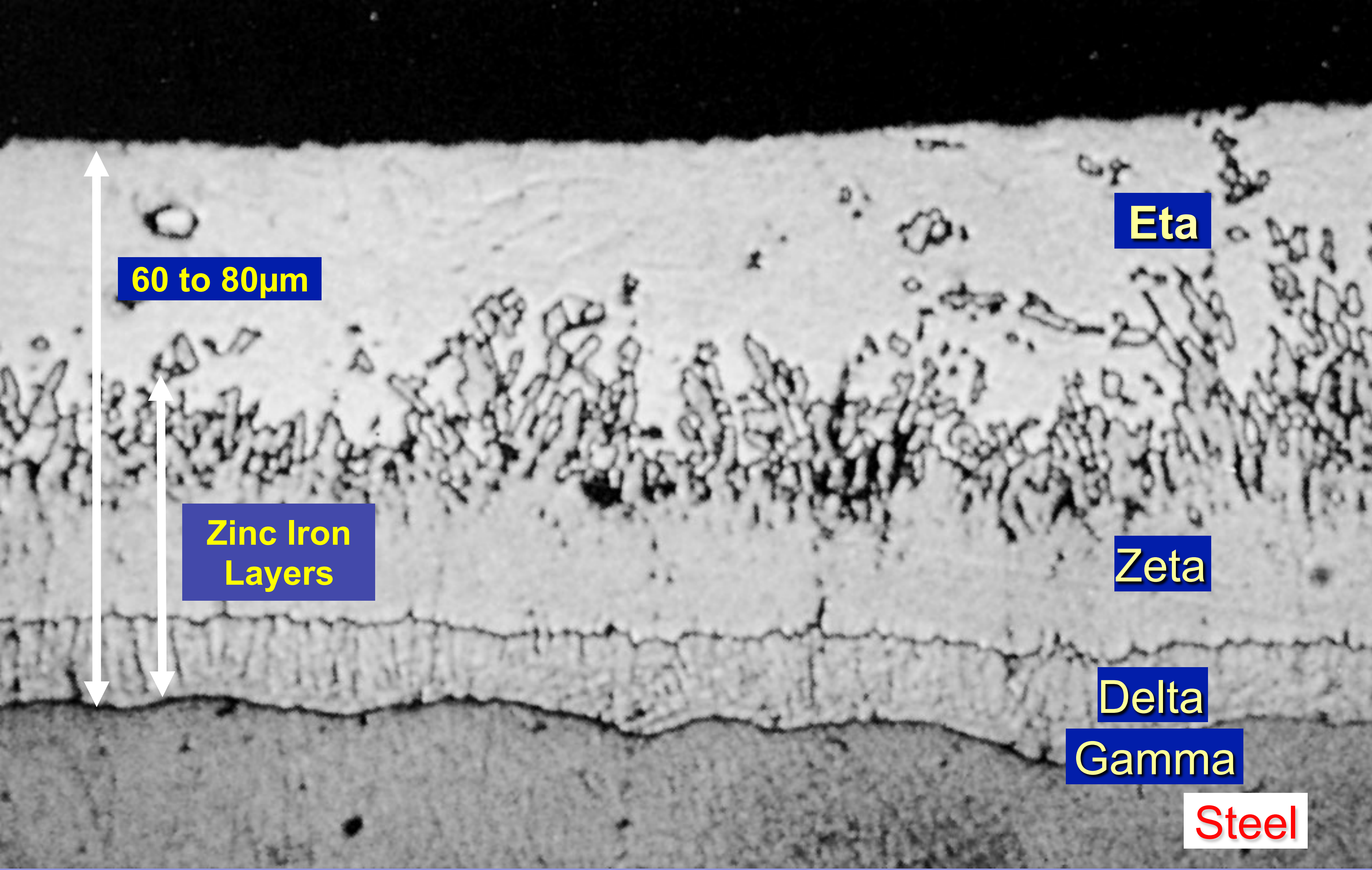
Zinc electro -ve = Anode

Zinc is electro –ve to carbon steel and therefore provides cathodic protection to carbon steel

How Does Zinc Protect?

- **Barrier Protection** **$ZnCO_3$** 1st Line of Defence
- **Cathodic Protection** **2ND Line of Defence**

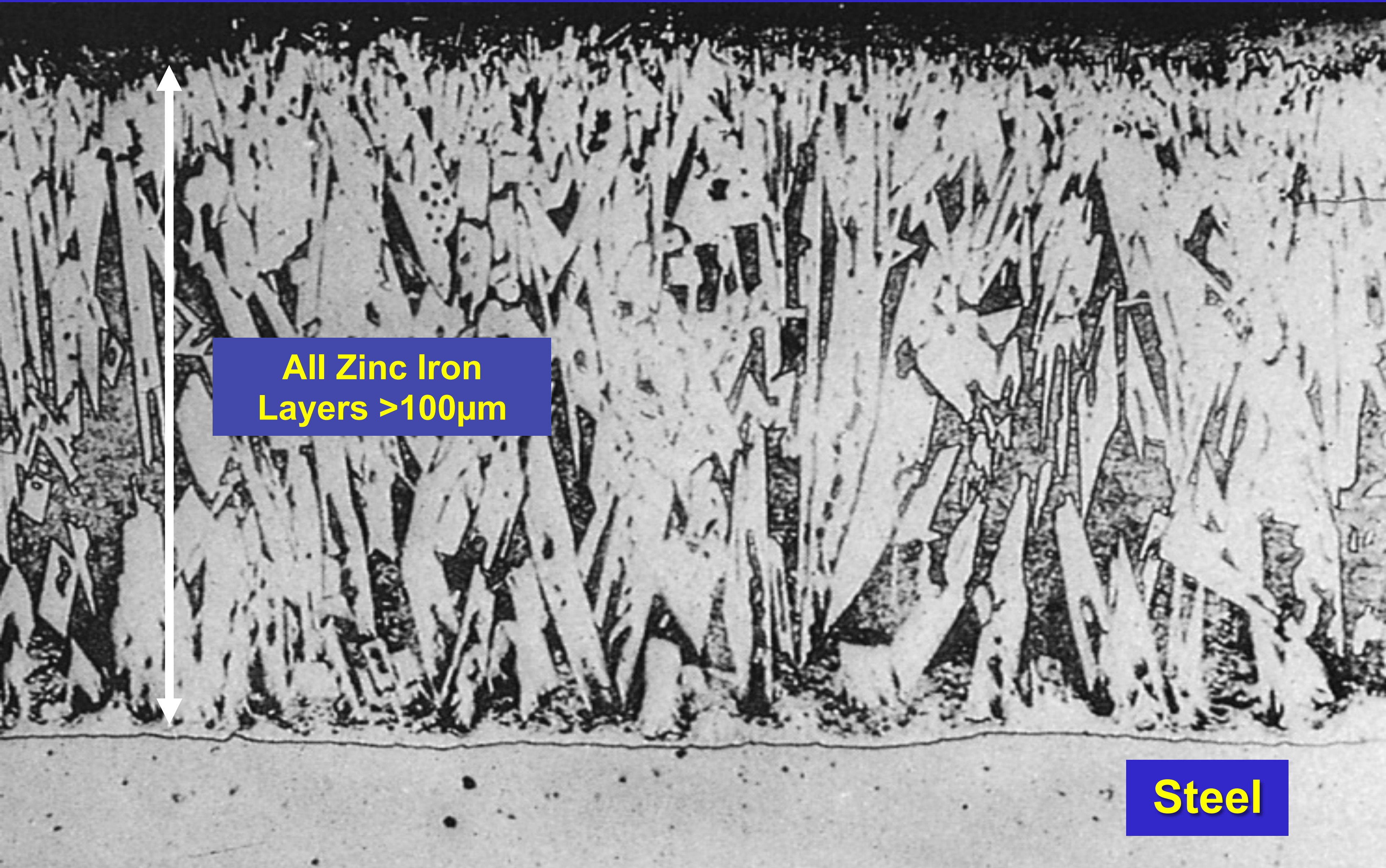
  Zn electro –ve to Carbon steel
- **Reduced rate of attack (Slowly corroding barrier referred to as Sacrificial Protection)**
- **Greater coating thickness of HDG versus electro-plating. (HDG 80µm – Zn Electro-plating <10µm) Thicker coatings Longer Service Life.**

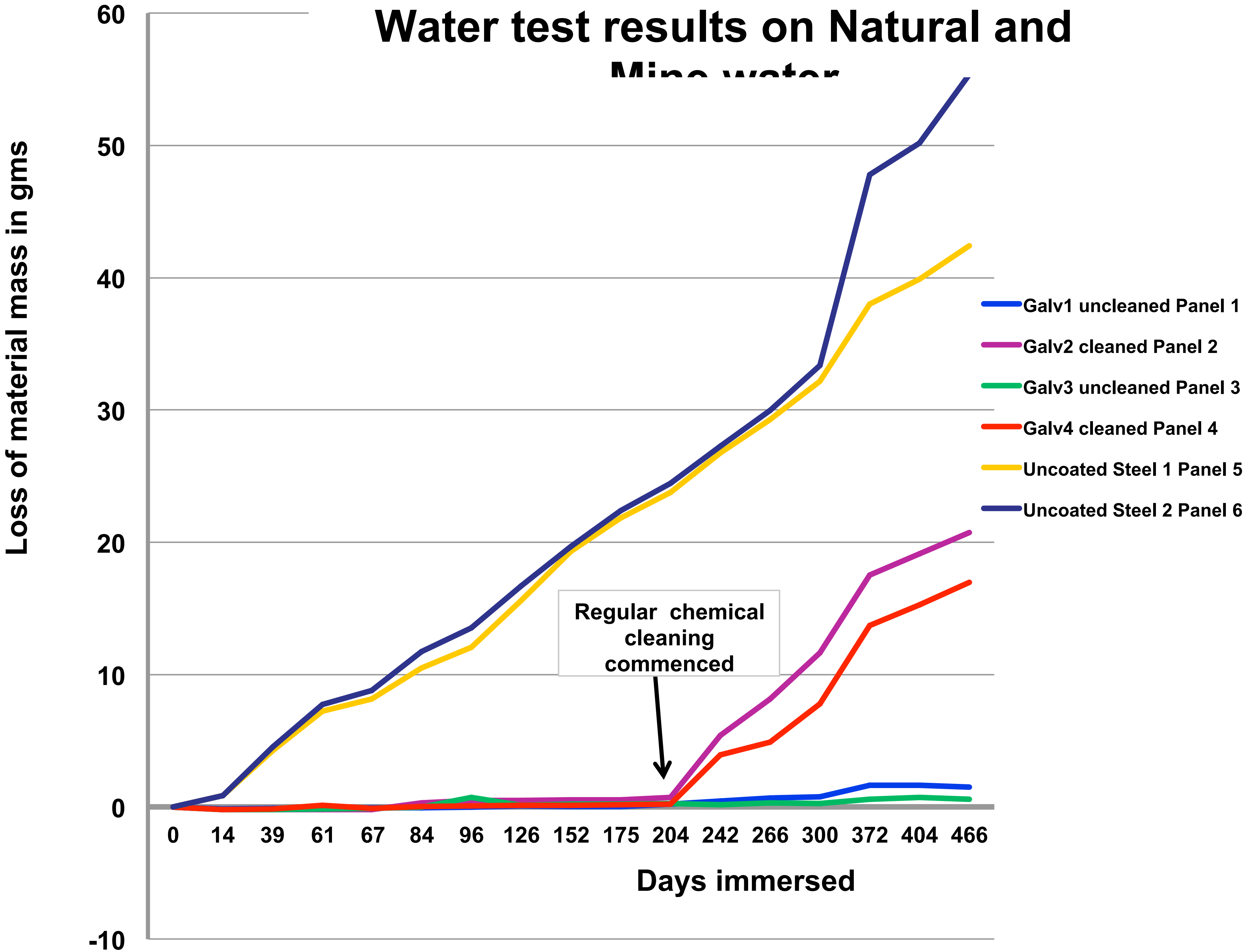


Typical Cross Section of HDG coating
Aluminum Killed Steel

Micrograph
x 150 Mag

Silicon-killed Steel 0.26% Si
Galvanizing Temperature 460°C





Water test results on Natural and Mine water
Loss of material mass in gms
60
50
40
30
20
10
0
-10
0 14 39 61 67 84 96 126 152 175 204 242 266 300 372 404 466
Days immersed
Regular chemical cleaning commenced
Galv1 uncleaned Panel 1
Galv2 cleaned Panel 2
Galv3 uncleaned Panel 3
Galv4 cleaned Panel 4
Uncoated Steel 1 Panel 5
Uncoated Steel 2 Panel 6

lwork prior to

Note that on the Buntons additional "sealer" coatings have been applied to over the fasteners

Shaft Guides Measured > 250µm

Early Shaft Inspections 2003 and 2006

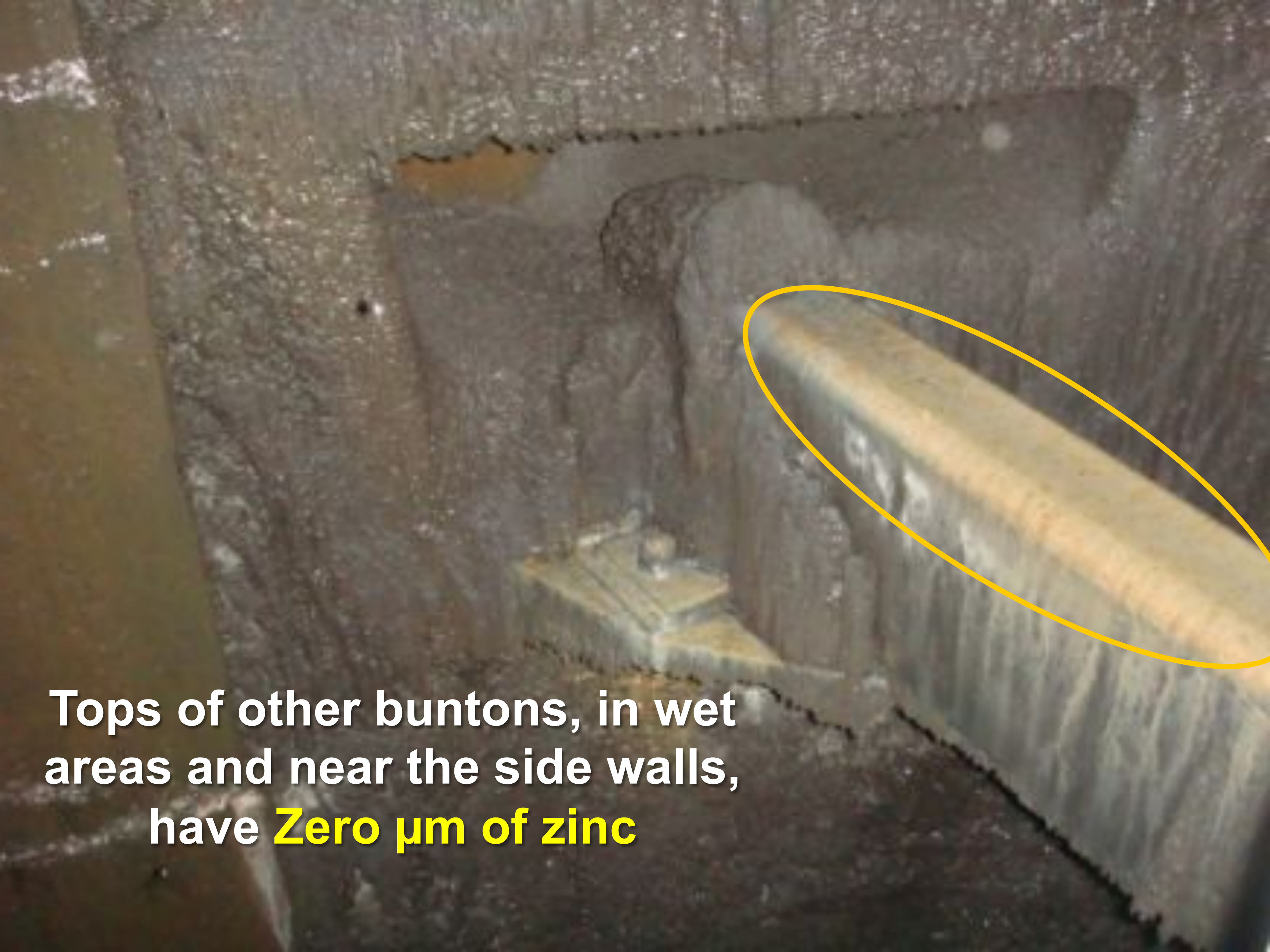
January 2003
Shaft Guides; Zinc was intact and being consolidated by the rolling action of the cage

September 2006

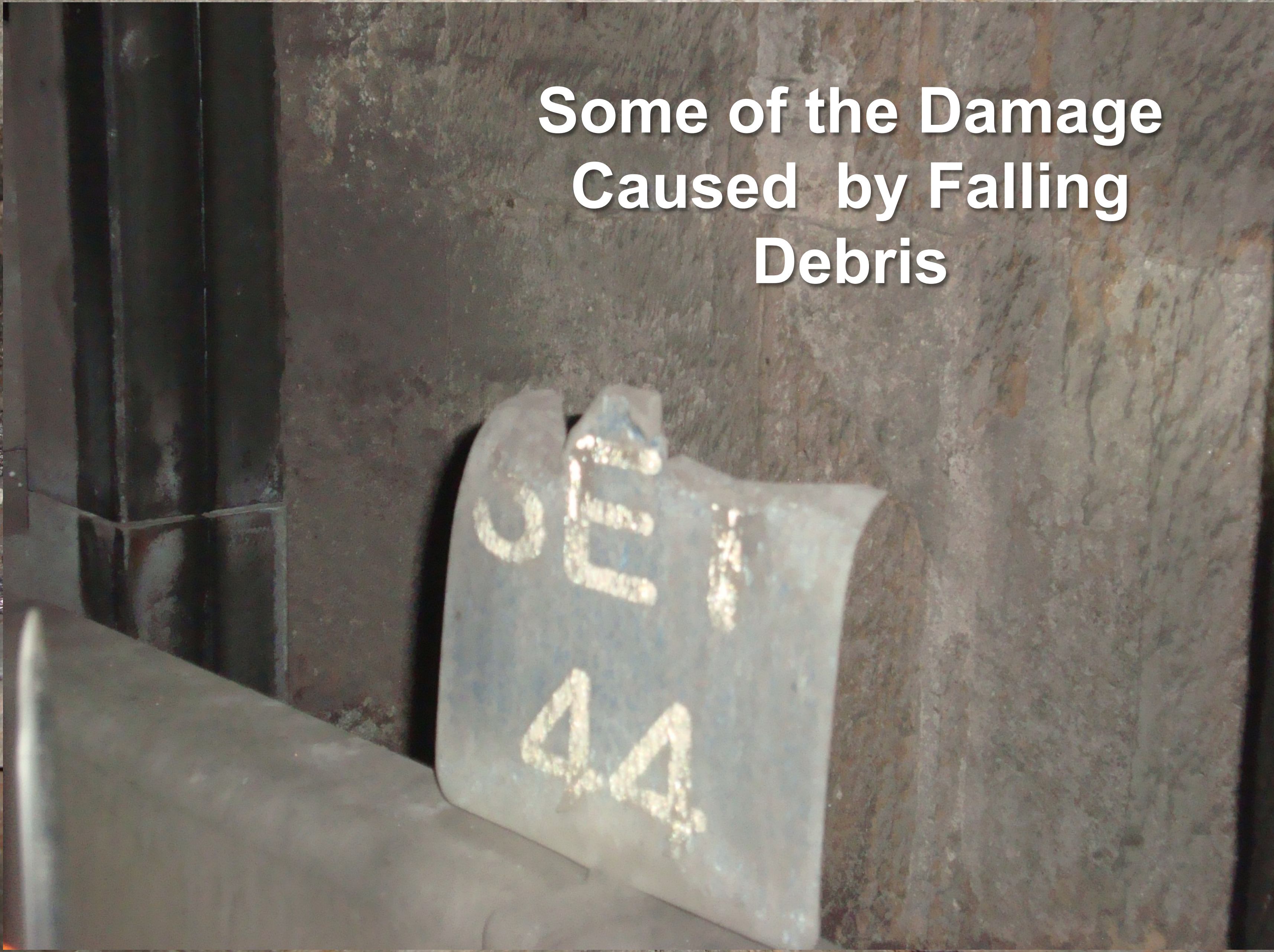
Measurement on the wearing surface of the guide, indicates 181µm of hot dip galvanized coating

Examination of a bunton, 256µm of zinc coating was measured. It is important to note the areas where these measurements were taken are “dry”


Side of Bunton 234µm
After 2 years in service
234
Fe
µm


Tops of other buntons, in wet
areas and near the side walls,
have Zero µm of zinc

Some of the Damage Caused by Falling Debris



After 2 years hot dip galvanized coating on a bunton "top" is being eroded and corrosion of the steel has commenced

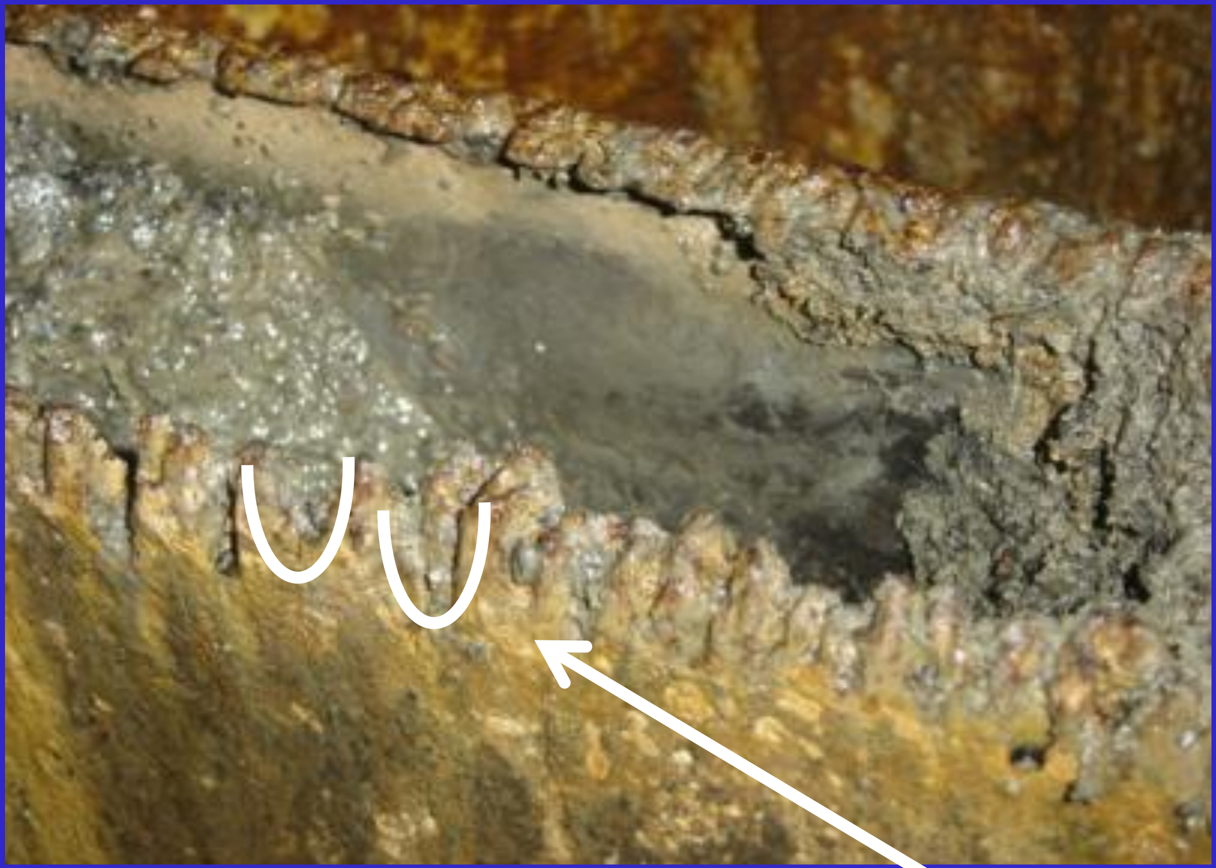
Durability Concerns After approximately 12 years Service

ion corrosion
the top of the
n continuous
air flow driven
vater droplets,
nd debris

1st line of defence, being the zinc carbonate layer, has been eroded away exposing the steel to erosion corrosion

More serious Erosion Corrosion of the bunton being destroyed (Always near the side wall)

Erosion Corrosion Characteristics



1. Saw-tooth edges of the bunton, a clear indication of erosion-corrosion.

2. Using zinc, under corrosion creep, down the side of the bunton and away from the exposed carbon steel, is impossible.

3. Impingement attack produces characteristic water-swept pits, often horseshoe shaped.

4. The leading edge of the pit is frequently undercut.

Damage to bunton tops relate to water “raining” down the shaft, supplemented by dust and debris impacting onto the top of shaft steelwork, usually close to the side wall

Abrasive materials from the mining process added into air stream is extremely abrasive resulting in erosion corrosion attack of bunton tops.

Corrosion control systems being eroded away, followed by **erosion corrosion** of steel until perforation

2 years in service

Sides and undersides of buntons retain near original hot dip galvanized protective coatings

From Mine 1

Why Erosion Corrosion?

- **Continuous flow** of oxygen rich water "raining" down a shaft, together with fine dust and occasional debris into the air stream, impacts onto the tops of buntons eroding the $ZnCO_3$ layer. This continuous cycle of removing $ZnCO_3$ and steel (Fe_2O_3) **RUST** continues to the point of perforation.

- **Abrasive materials** from the mining process carried down in the air stream produces a blasting effect onto the cross shaft steel, usually found near the side walls.

- **Erosion** of the ***barrier protection*** **($ZnCO_3$)** followed by corrosion and erosion corrosion products (red rust) of carbon steel.

- Only the **tops of buntons** are being seriously attacked. Sides and undersides of buntons retain near original hot dip galvanized protective coatings.

- Corrosion control provided by hot dip galvanizing ,is withstanding **environmental conditions** found within shafts visited.

- **Erosion corrosion** varies from relatively minor near the shaft surface and increases as one proceeds down the shafts.

The Erosion Corrosion Process

- The **zinc carbonate** ($ZnCO_3$) protective patina is unable to form due to the continuous impingement of oxygen rich water. All the zinc products of corrosion are eroded away until all the zinc has been consumed.

- Steel is exposed, forming loosely adhering layers of **iron hydroxide** (Fe_2O_3 & $Fe(OH)_3$) "red rust", which is then easily eroded away.

- This **cycle of events** will continue as long as the water rains down the shaft and the bunton tops are unprotected.

- Hot dip galvanized coatings remain operational on the bunton sides, undersides as well on the internal surfaces, indicating effective corrosion control.

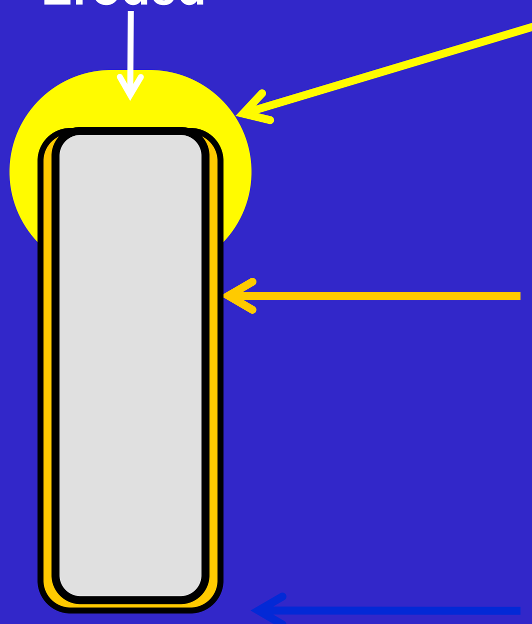
Proposed Corrective Actions

- Eliminate as much water as possible from **raining** down the shaft. Employ a series of gutters to collect and divert the water to a collection point.

- Install a **Duplex coating system** over the top of the buntons, shaped to deflect falling particles or designed to absorb impact from water, water borne minute particles and small debris.

Diagram of a potential solution to the erosion/corrosion situation

Zinc
Eroded



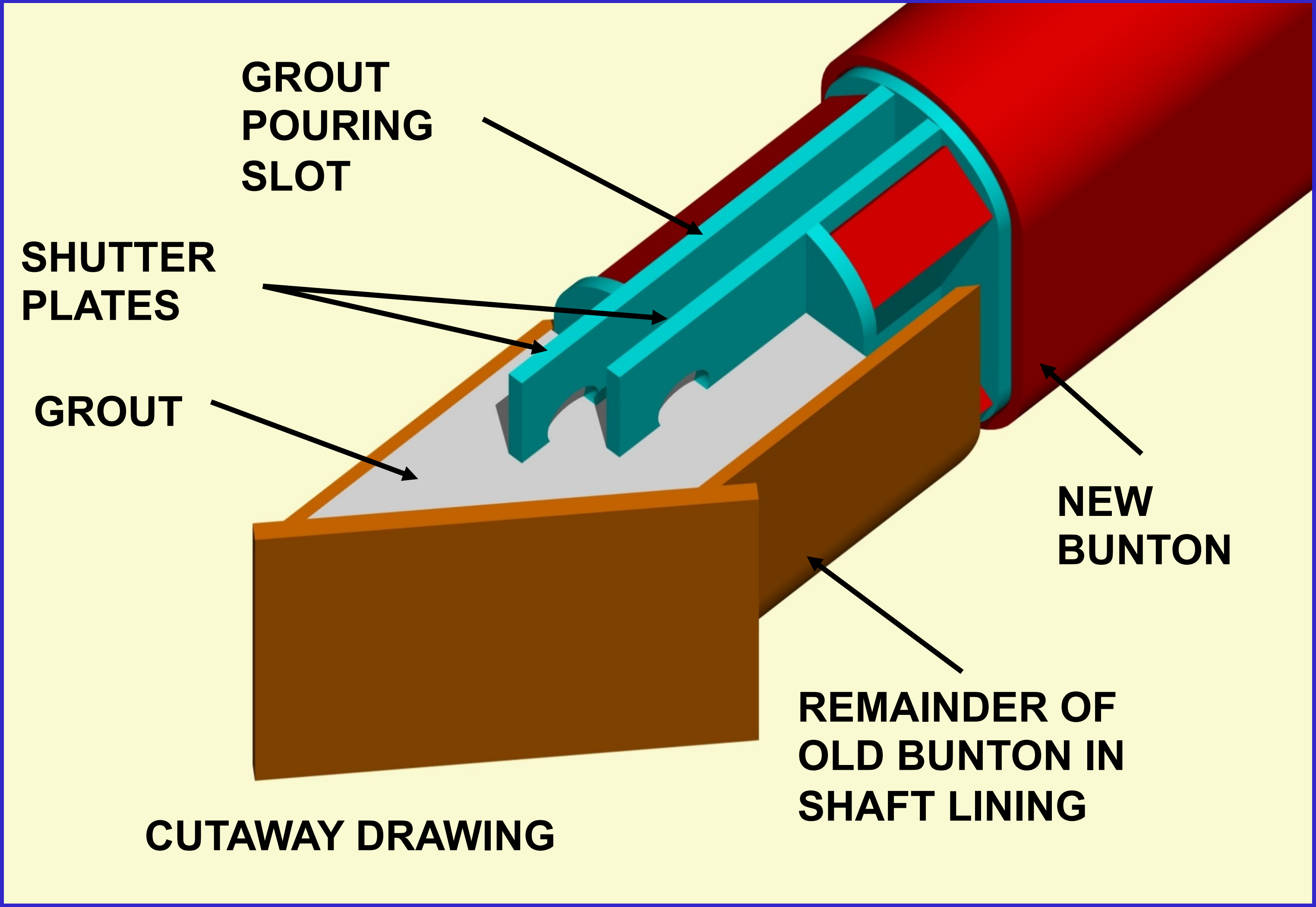
Protective “top shield” to withstand the erosive actions of continuous “raining water” containing potentially abrasive solids generating a blast effect.

Hot dip galvanized coating found to be intact with the exception of the bunton top.

Consider the use of a Duplex system for an extended operational service life.

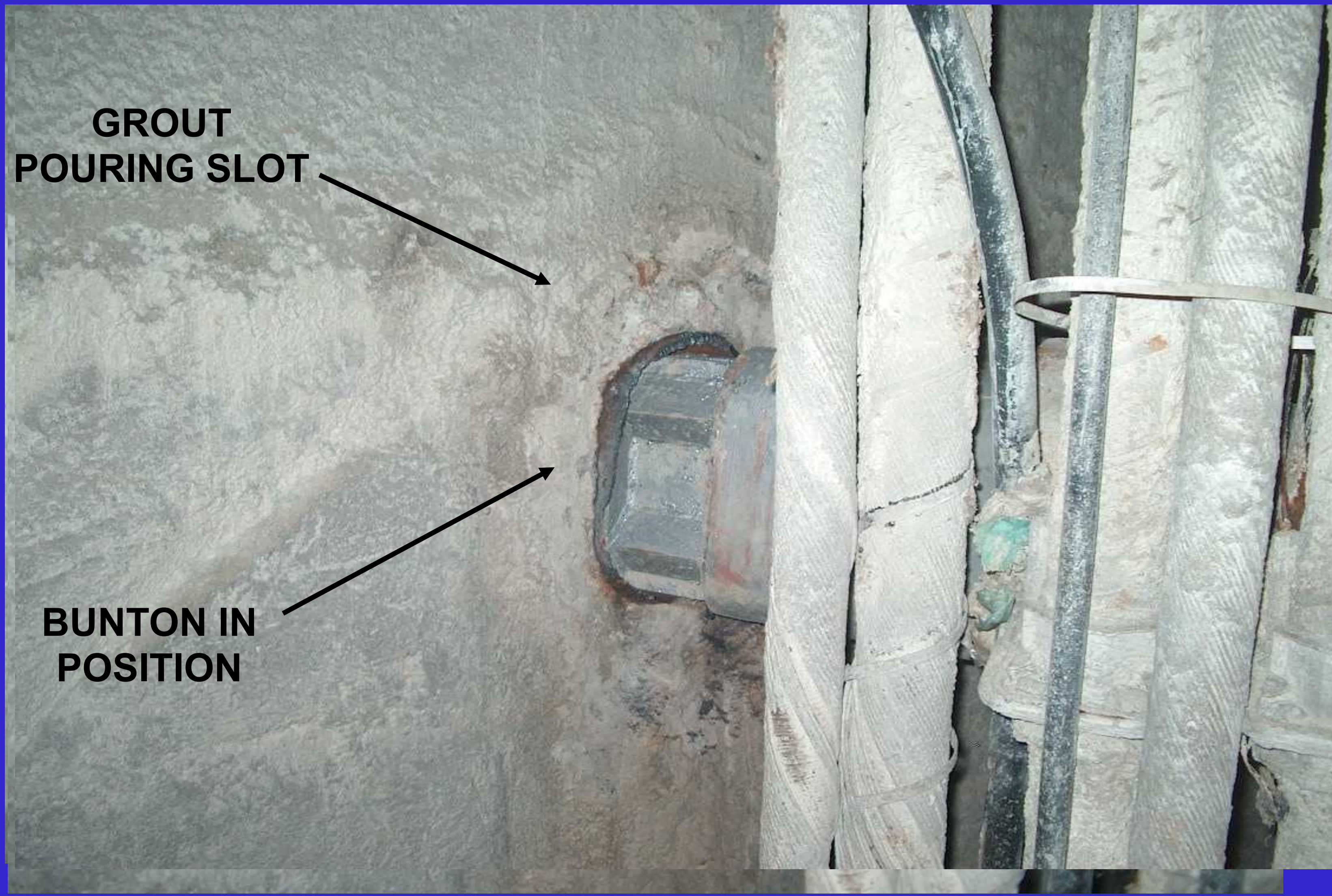
The sketch represents an existing bunton with no zinc over the top of the bunton

POSSIBLE SOLUTION FOR BUNTONS REPLACEMENT



Reference Nordbak (Pty) Ltd
technical.nordbak@global.co.za

REPLACEMENT PROCESS



Reference Nordbak (Pty) Ltd

Conclusion and Questions

- Hot dip galvanizing, on its own, is adequate in providing corrosion control in the shaft environment.

- Water “raining” down the shaft, supplemented by minute particles, is subjecting the tops of buntons to a process of **erosion-corrosion**.

- Dry areas within the shaft are also exhibit erosion, due form air borne solids, but to a far lesser extent than in the wet areas.

- No bacterial corrosion was identified, even though the quality of the water could support the development of this form of corrosion.

Acknowledgements

- “Practical Guidelines for Corrosion Protection in the Mining & Metallurgical Industry” by R.H.C. Andrew published by NACE International 1997.
- “Corrosion Resistance of Zinc and Zinc Alloys” by Frank Porter. published 1994 by Marcel Dekker Inc.
- PhysMet cc. Various extracts from a series of site visit reports.
- Hot Dip Galvanizers Association Southern Africa case studies.
- “Fundamentals of Metallic Corrosion” Atmospheric and Media Corrosion of Metals by Phillip A. Schweitzer Published CRC Press Taylor & Francis 2007
- Staff at the mines visited

Thank You for your Attention