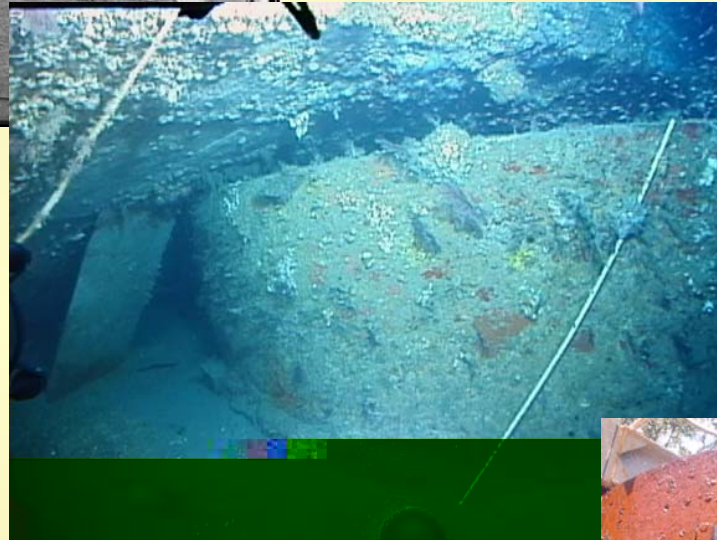
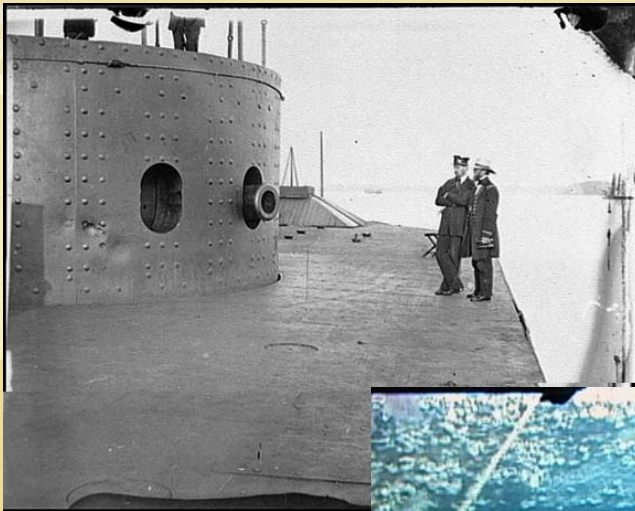


Investigation of the Corrosion of USS Monitor Artifacts

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Old Dominion University

Curtiss Peterson
Mariners' Museum



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The Mariners' Museum.

This presentation is available at
www.physics.odu.edu/cmpp
www.RustDr.com

Corrosion of the USS Monitor

Goals:

- **General Corrosion Evaluation**

- Turret
- Cannons
- Engine and Condenser

- **As a result of**

- Submerged Saltwater exposure for 150 years
- Recovery and Exposure to Air.

- **Use Spectroscopic Analysis**

- Rust identification, Source and Corrosion Rate
- Correlate rust formation with the exposure conditions.

Iron Corrosion

Recipe for Rust

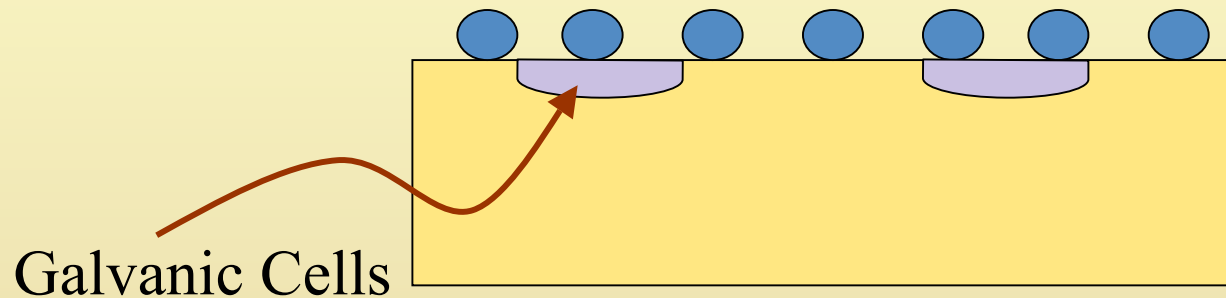
Fe → 2 parts

O → 3 parts

Add H₂O and Salt to taste

- Goethite → α -FeOOH

- Akaganeite → β -FeOOH



Corrosion Evaluation

Spectroscopic Identification of rust composition:

- Iron Oxide Identification
- Oxide Mapping
- Impurity (pollutant) content

Analytical Techniques:

- X-Ray Diffraction
- Mössbauer Spectroscopy
 - --Transmission and Scattering
- Micro-Raman Spectrometry
- Electron Micro-Probe
- Ion Chromatography
- XAFS
- IR/UV Spectroscopy
- Ion Transport
- Electrochemical Impedance Spectroscopy

Turret rust

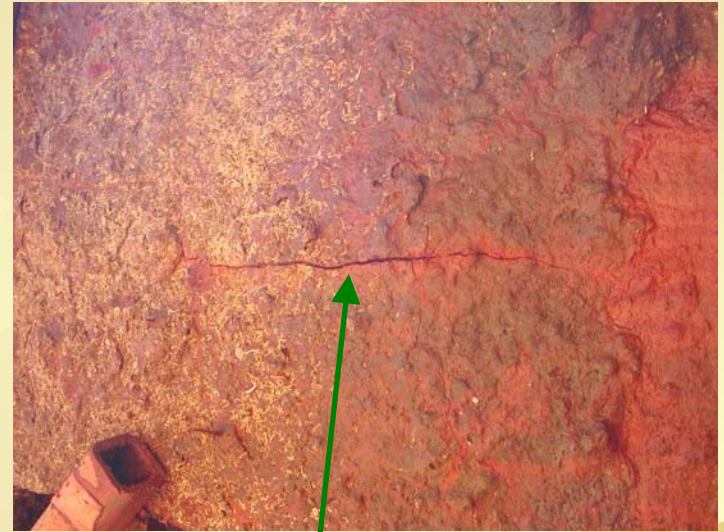
High Time-of-Wetness, Low oxygen, Chlorides



Turret Corrosion

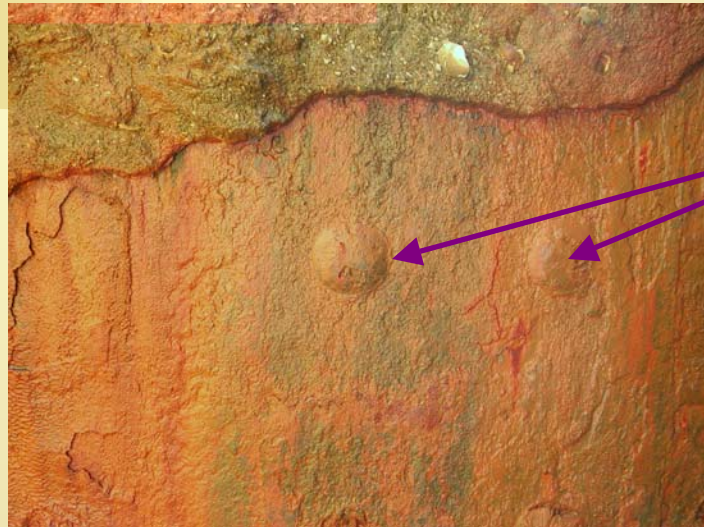


Bleeding



Marine Growth: Cracking

Bolt Heads



Intact



Corroded

Turret Corrosion



**Submerged Corrosion Environment
(Anaerobic and salt-water)**

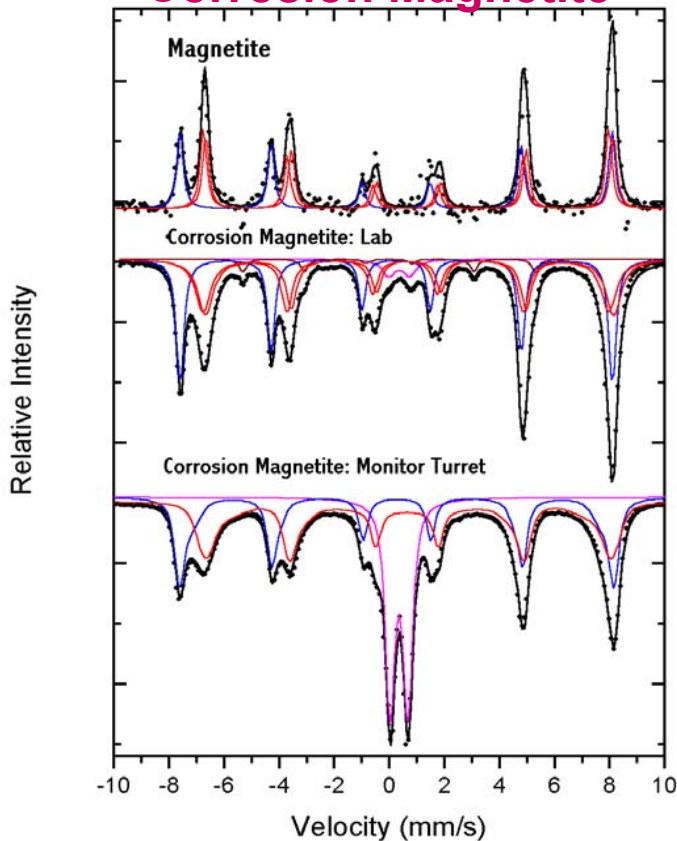
Cannon Rust



USS Monitor Turret Rust: Mössbauer Analysis

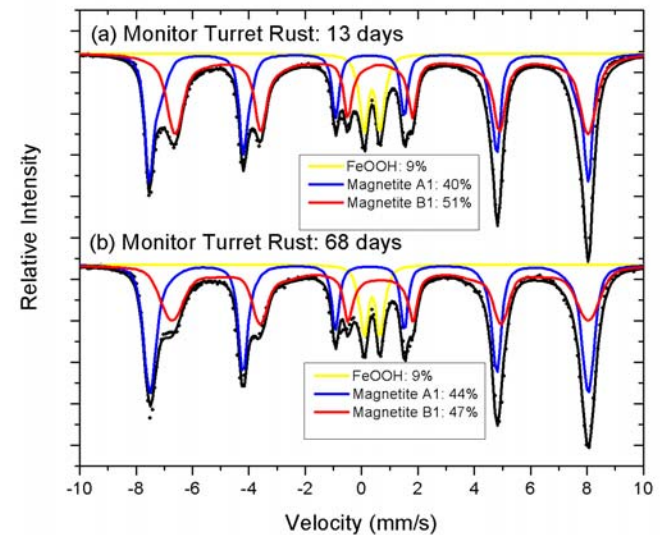
Magnetite: $\text{Fe}_3\text{O}_4 \rightarrow$ Maghemite: $\gamma\text{-Fe}_2\text{O}_3$

A new corrosion product: Corrosion Magnetite

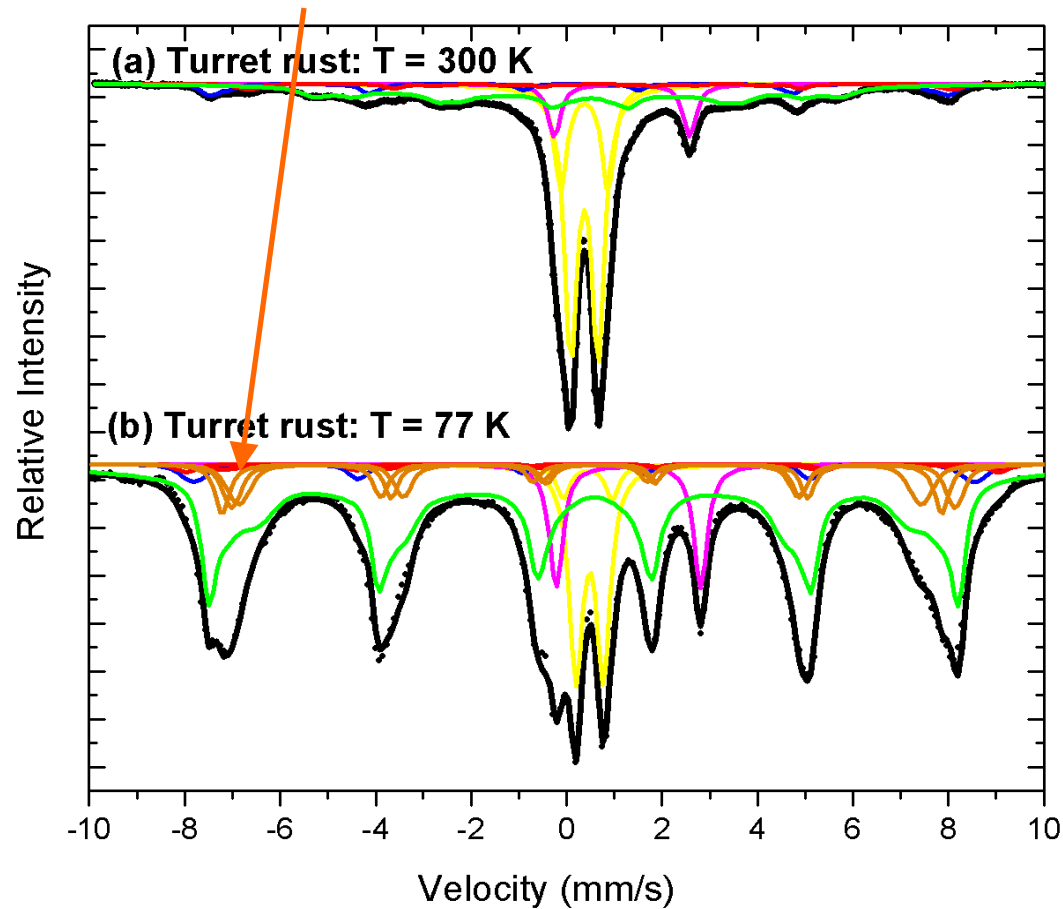


Corrosion Magnetite is unstable

As the magnetite ages,
the **B1 site** oxidizes to the **A1 site**.



**Exterior Turret Rust: Magnetite, Lepidocrocite, Goethite,
Akaganeite +FeSiO₄ and CaCO₃**



**Corrosion mainly due to high TOW (submersion)
But exposure to air produces Akaganeite with bound chlorides**

Ocean sediments

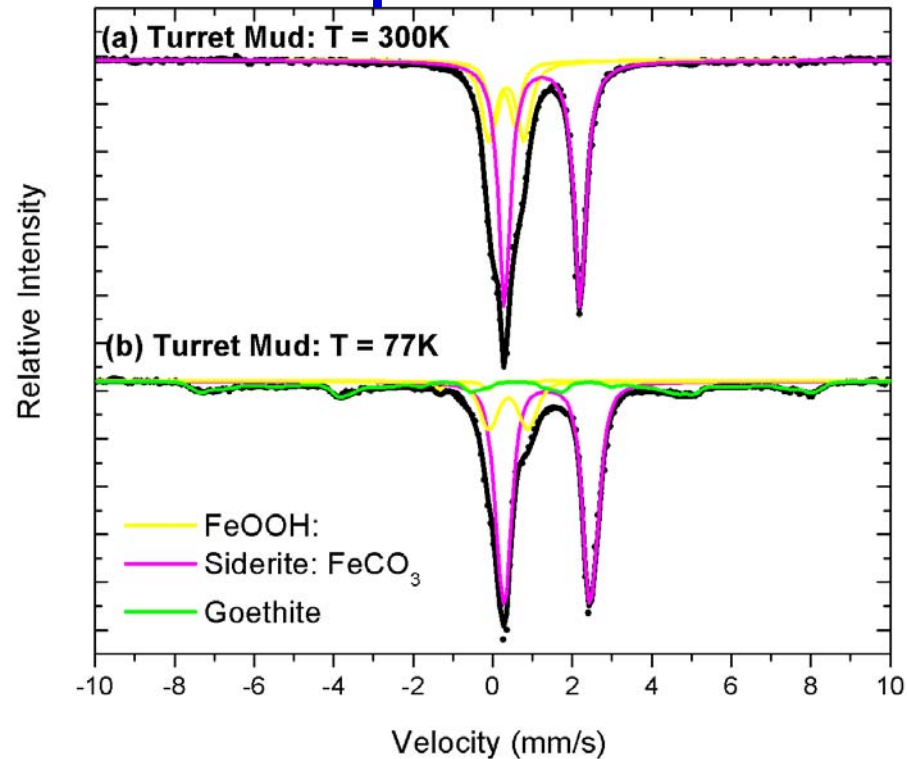


Exterior Turret Wall



Behind Nutguards

Turret Mud: FeCO₃, CaCO₃, Quartz
+ Lepidocrocite, Goethite
+ 1.5% Sulfur compounds.....MIC???
pH = 2-3



Turret Wall Thickness: Corrosion Rate

Turret Construction:

Diameter: 20 ft.

Construction: Wrought Iron: 8 layers, each 1" thick, Bolted



Thickness measurements: Outer and Inner sheets = $\frac{3}{4}$ "

Thickness loss = $\frac{1}{4}$ " (250 mils) in 140 years

= $1 \frac{1}{2}$ - 2 mils per year (mpy).

(Compared with bridge corrosion 2 mpy = very adverse chloride environment
2 mpy = 5-10X expected corrosion of steel).

Conclusion: Corrosion rate of the turret has been high.

Need to map wall thickness above and below mud line



Rusticles

On Engine and Condenser



Composition:

Outer Case: CaCO_3

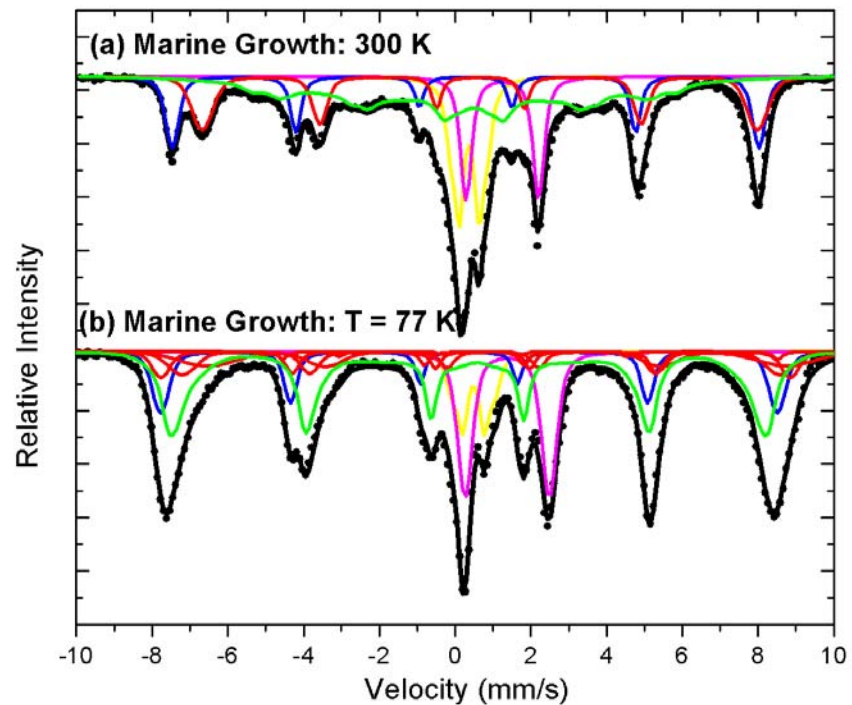
Inside: Mainly Corrosion Magnetite

This is in variation with Rusticle analysis on the Titanic.

Marine growth



**Turret Marine Growth + Rust: FeCO_3 , CaCO_3 , Quartz
+ Magnetite, Goethite, Lepidocrocite**



Conclusions:

During seawater submersion of Wrought and Cast Iron

- Corrosion Magnetite forms
- Unstable and oxidizes to Maghemite
- Corrosion rate very high
- Sediments exhibit low pH = 2-3
- Possible Microbial Induced Corrosion.

Exposure to air

- Akaganeite (with bound chloride) forms.

What's Needed?

- A new technology for removing (all) chlorides from the iron
 - Plasma induced chloride diffusion
 - Super Critical Fluid extraction
- Adequate funding to develop improved conservation technology for this and the next important archeological projects .



9 September 2004