Data Center Cooling System Failure

CRAH – Computer Room Air Handler Coils

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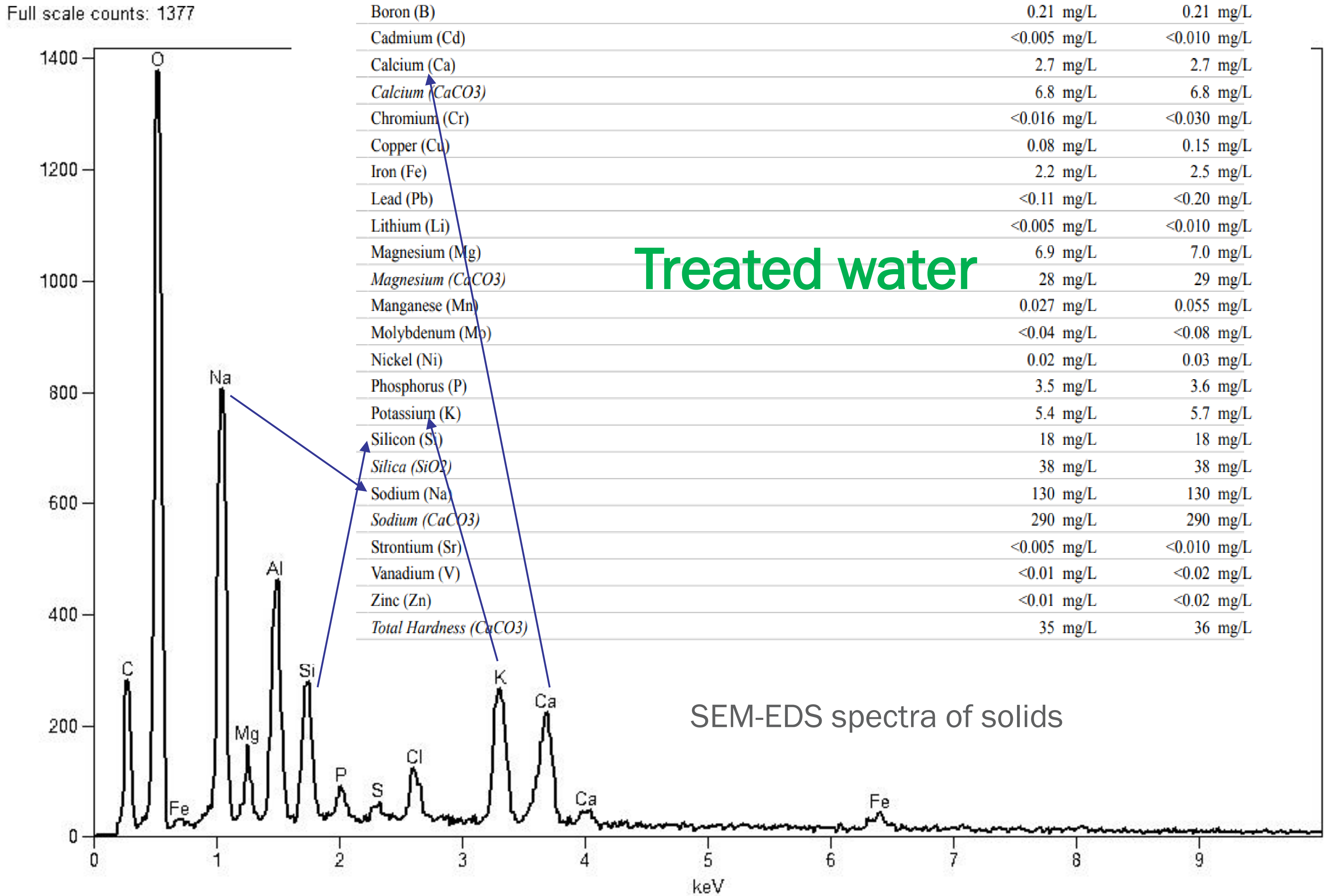
Background Information

- Low flow through copper coils (0.5 ft/s).
- Stagnant flow, long idle periods due to startup delays and variable use and CRAH rotation.
- Low and stagnant flow in carbon steel chilled water supply piping.
- TES tank issues.
- Treatment program includes PSO (phosphonate), orthophosphate, silicate, benzotriazole, non-oxidizing biocides, caustic (pH control) in softened water.
- Molybdate prohibited due to discharge restrictions. Nitrite not used due to bacteria growth concerns.

Chilled water leak in CRAH coil with cooling water and water solids on fins and in condensate drip pan

Cations - Metals	Test Method: CW14024	Filtered	Total
Aluminum (Al)		<0.03 mg/L	<0.06 mg/L
Barium (Ba)		<0.005 mg/L	<0.010 mg/L
Boron (B)		0.21 mg/L	0.21 mg/L
Cadmium (Cd)		<0.005 mg/L	<0.010 mg/L
Calcium (Ca)		2.7 mg/L	2.7 mg/L
Calcium (CaCO3)		6.8 mg/L	6.8 mg/L
Chromium (Cr)		<0.016 mg/L	<0.030 mg/L
Copper (Cu)		0.08 mg/L	0.15 mg/L
Iron (Fe)		2.2 mg/L	2.5 mg/L
Lead (Pb)		<0.11 mg/L	<0.20 mg/L
Lithium (Li)		<0.005 mg/L	<0.010 mg/L
Magnesium (Mg)		6.9 mg/L	7.0 mg/L
Magnesium (CaCO3)		28 mg/L	29 mg/L
Manganese (Mn)		0.027 mg/L	0.055 mg/L
Molybdenum (Mo)		<0.04 mg/L	<0.08 mg/L
Nickel (Ni)		0.02 mg/L	0.03 mg/L
Phosphorus (P)		3.5 mg/L	3.6 mg/L
Potassium (K)		5.4 mg/L	5.7 mg/L
Silicon (Si)		18 mg/L	18 mg/L
Silica (SiO2)		38 mg/L	38 mg/L
Sodium (Na)		130 mg/L	130 mg/L
Sodium (CaCO3)		290 mg/L	290 mg/L
Strontium (Sr)		<0.005 mg/L	<0.010 mg/L
Vanadium (V)		<0.01 mg/L	<0.02 mg/L
Zinc (Zn)		<0.01 mg/L	<0.02 mg/L
Total Hardness (CaCO3)		35 mg/L	36 mg/L

Treated water



SEM-EDS spectra of solids

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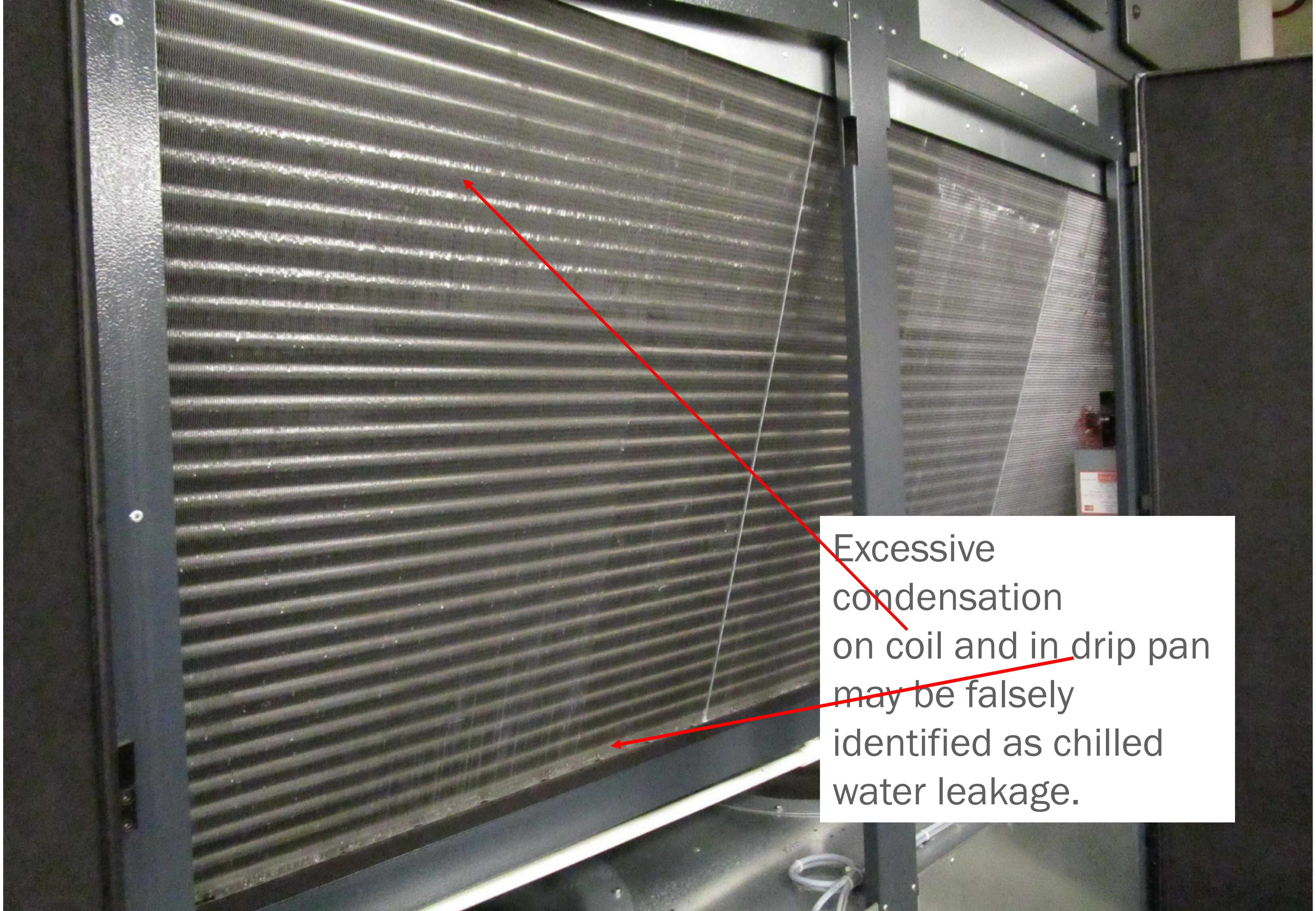
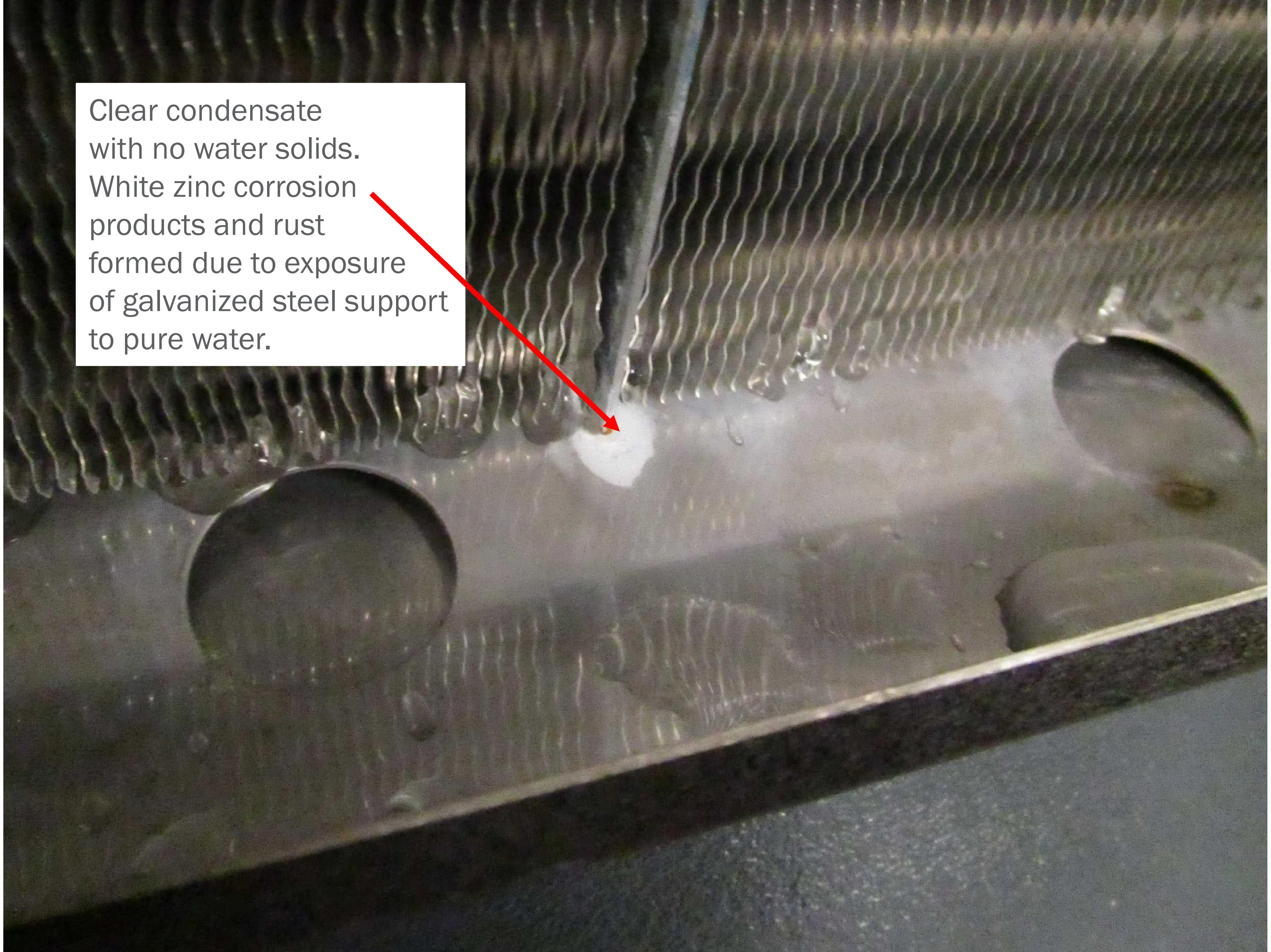


Excessive condensation on coil and in drip pan may be falsely identified as chilled water leakage.


Clear condensate
with no water solids.
White zinc corrosion
products and rust
formed due to exposure
of galvanized steel support
to pure water.


Zinc plating consumed from galvanized steel surface exposing steel which subsequently rusted

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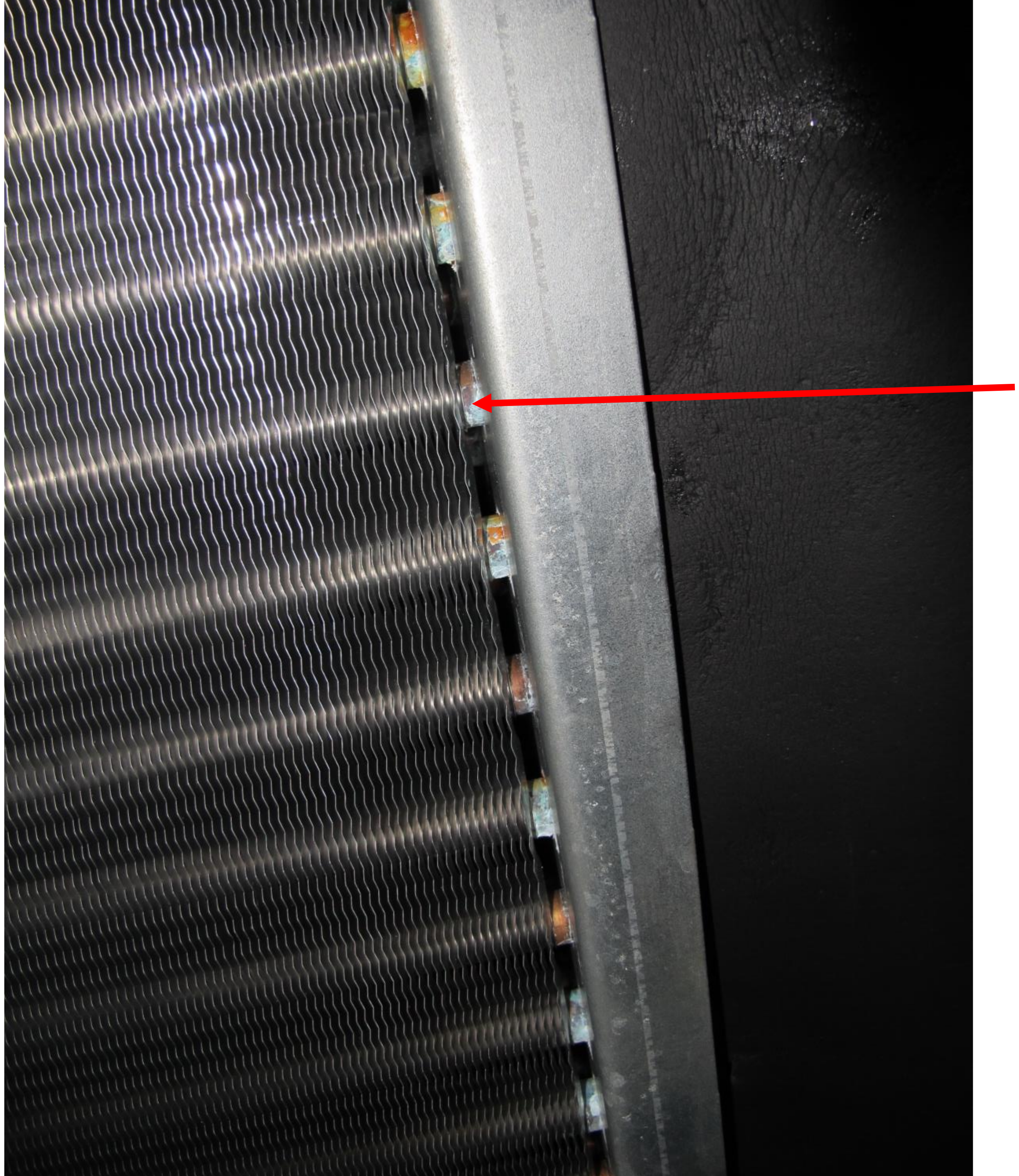

U-bends and/or headers on opposite side of tubesheet. Green patina indicates condensation on coil tubes and superficial atmospheric corrosion.


Green copper corrosion products from copper inlet header and tubes. Dissolved copper ions in condensate will plate out and promote galvanic corrosion of zinc on galvanized steel and on aluminum fins.

Thermal Energy Storage (TES) Tank stored 500,000 gallons to provide hours of cooling in case chillers shut down. The tank was internally lined with epoxy, but flow inside was essentially stagnant. The tank was not cleaned prior to startup as required because of delays. Consequently, five feet of sludge accumulated on the bottom.

No filters were installed at the outlet as mandated by ASHRAE. The sludge contained substantial amounts of iron oxide, and aerobic bacteria counts were high until after startup when it was shock treated with a bromine product.

The tank wasn't cleaned until at least 7 years following startup, assisted by divers.

TES Tank before System was Commissioned

MICROBIOLOGICAL ANALYSIS

PHYSICAL APPEARANCE

Physical State	Color of Sample	Solids	Color of Solids
Liquid	Colorless	Sediment	Brown

Analyte	Result		Test Method
AEROBIC BACTERIA			CB22010
Total Viable Count @ 35°C	900000	CFU/mL	
Pigmented Bacteria	1 Type		
Mucoid Bacteria	Detected		
Total Coliforms	<100	CFU/mL	
E. Coli	<100	CFU/mL	
Pseudomonas spp @ 35°C	690000 est.	CFU/mL	
ANAEROBIC BACTERIA			CB22016, CB22018
Sulfate Reducing bacteria	<1	CFU/mL	
FUNGI			CB22015
Mold	60 est.	CFU/mL	
Yeast	<10	CFU/mL	

- High aerobic bacteria counts.
- No SRBs or other corrosive bacteria.
- Shock treatment brought bacteria
  levels under control

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Higher iron concentration in recirculating chilled water due to poor maintenance of TES tank and low and stagnant flow through carbon steel piping

One of the coils failed a pressurized air leak test at two locations

- Leaks at end-most tubes connecting unsupported headers to coil tubes.

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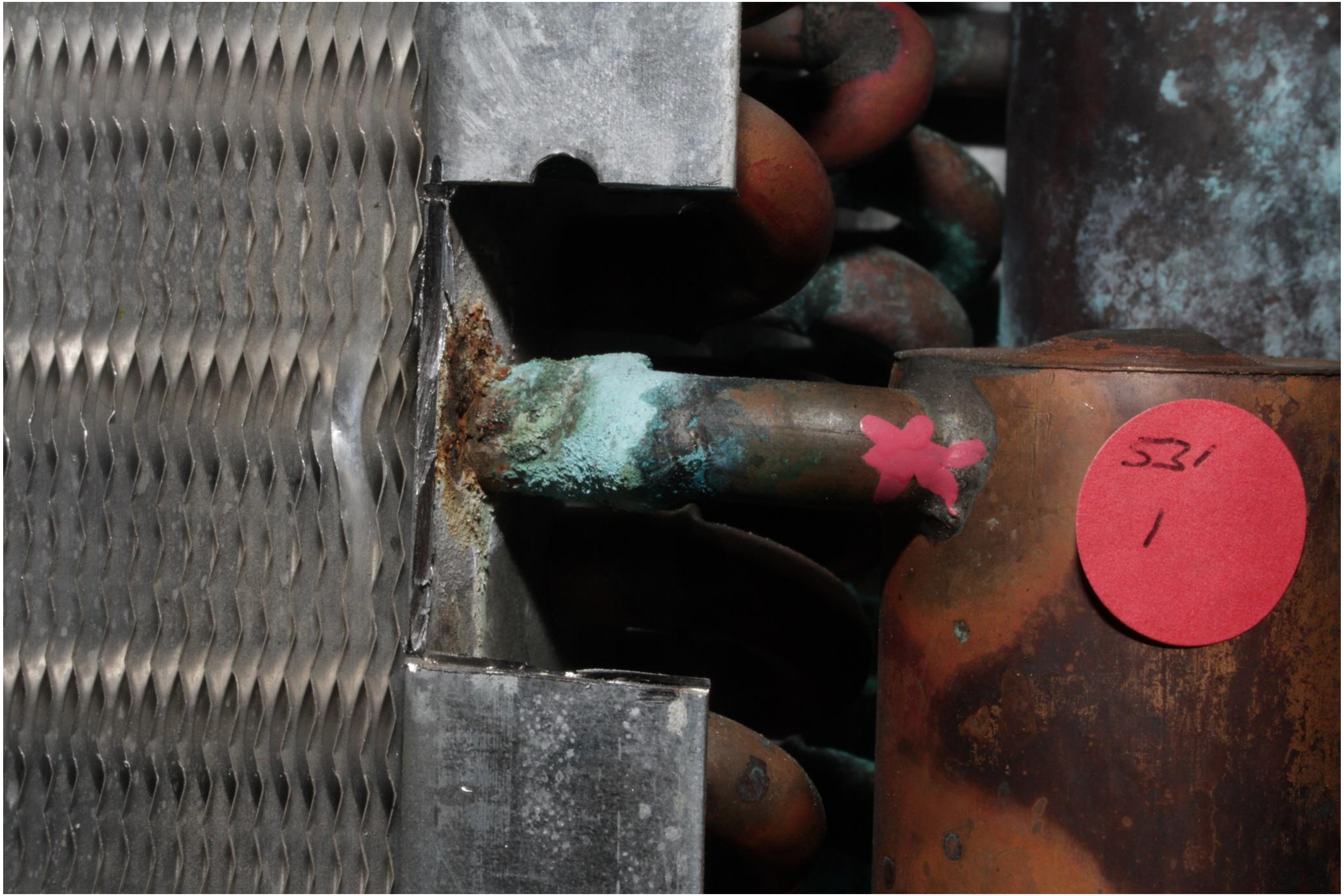

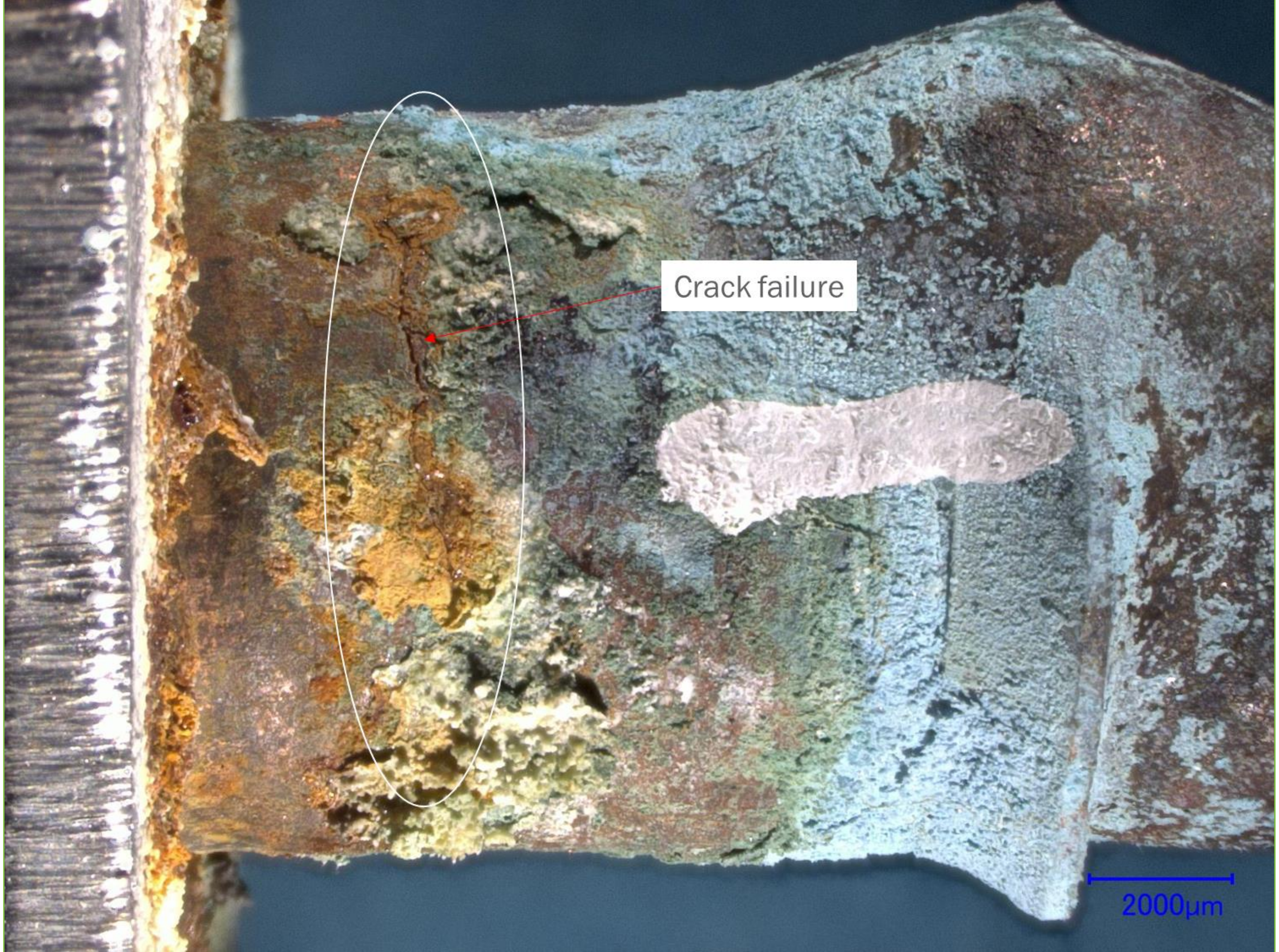
Crack failure
2000μm

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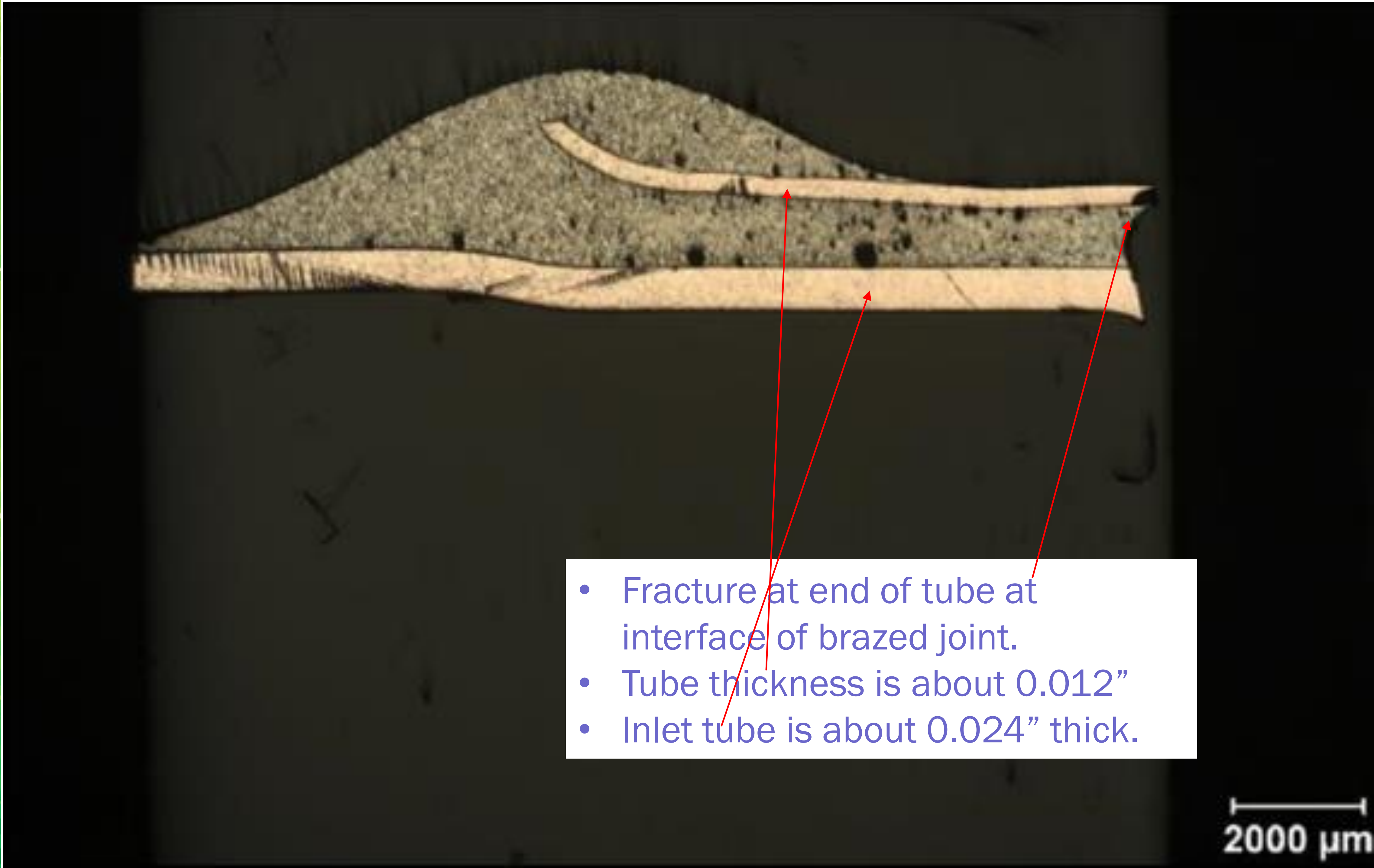
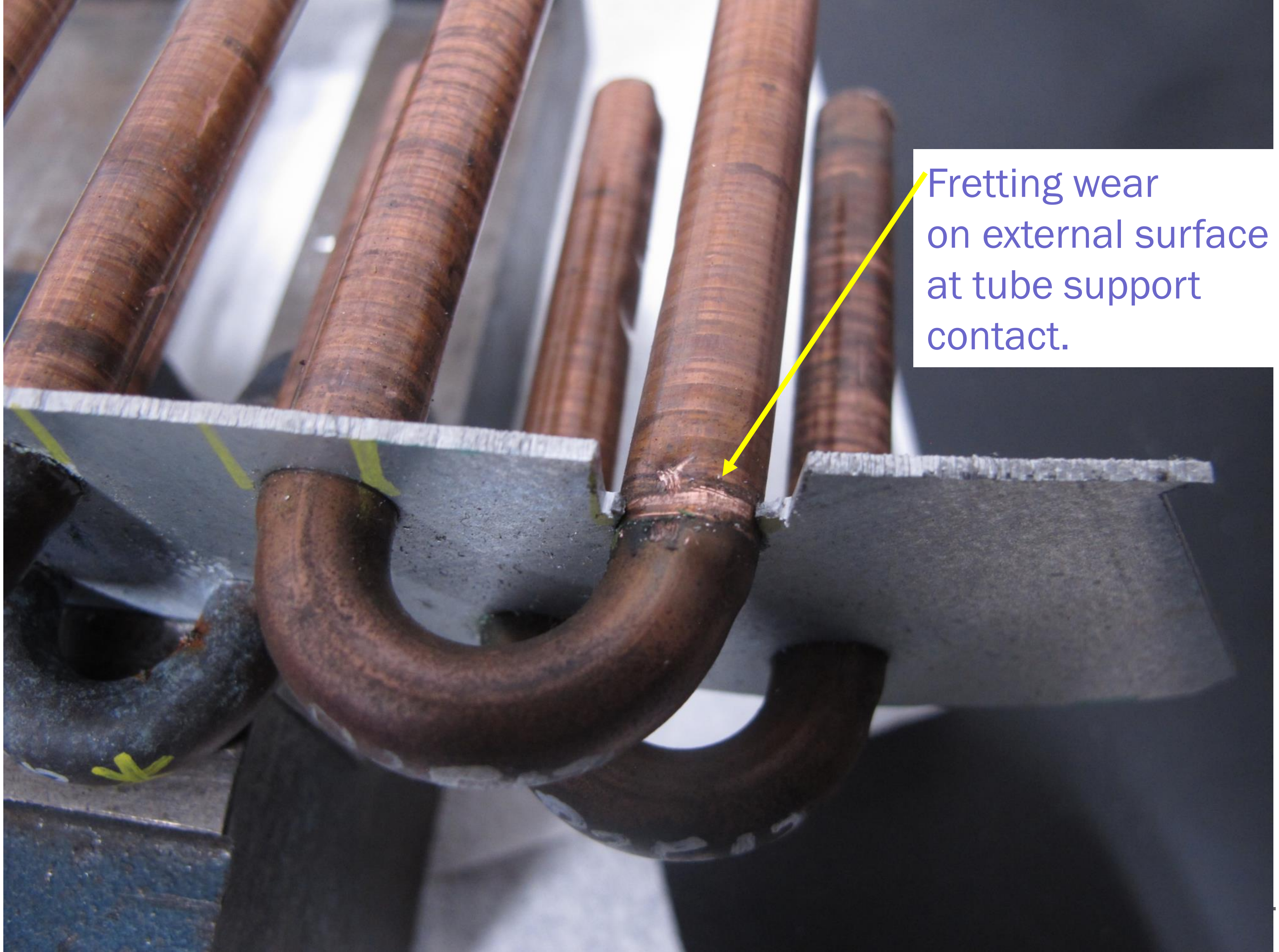
Internal deposits but no corrosion. Failure caused by fatigue cracking due to cyclic mechanical stresses by vibration, bending, expansion and contraction. Crack formed at point of stress concentration at sharp edge of brazed joint

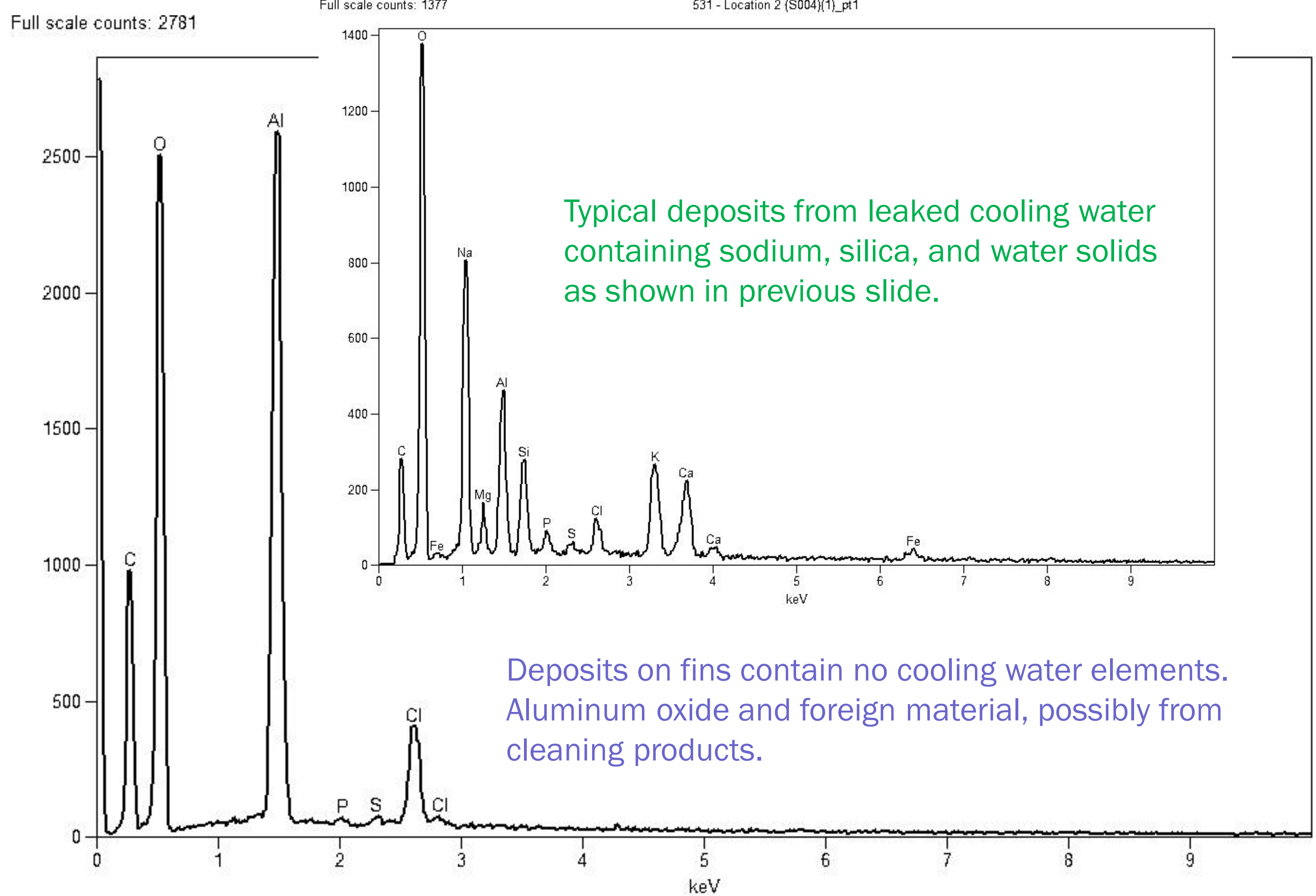


- Fracture at end of tube at interface of brazed joint.
- Tube thickness is about 0.012”
- Inlet tube is about 0.024” thick.

Through-crack at galvanized steel header contact point. Fatigue crack at point of rigid restraint. No internal surface corrosion.

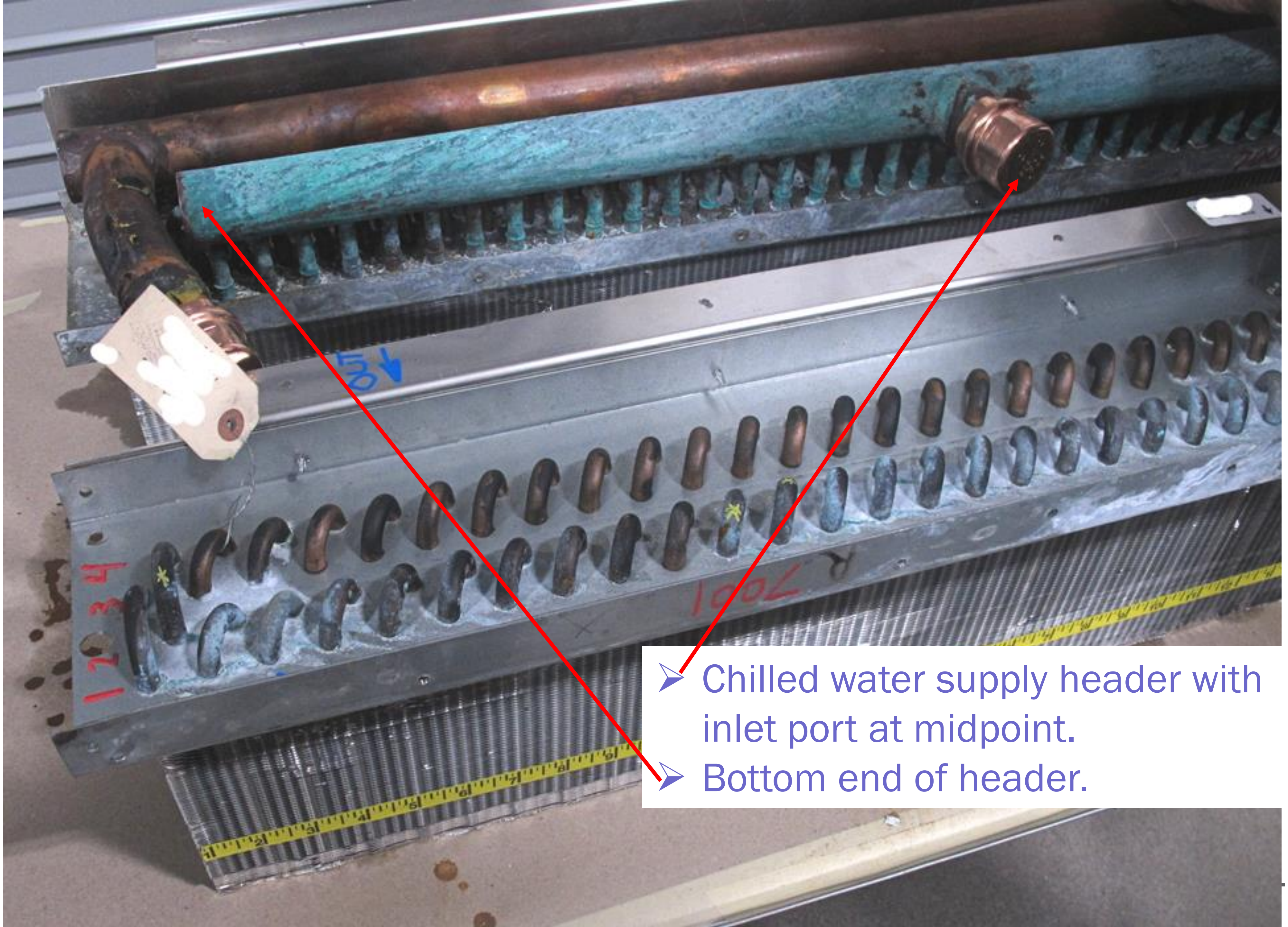

Fretting wear
on external surface
at tube support
contact.

Stains suspected to be cooling water leak sites.



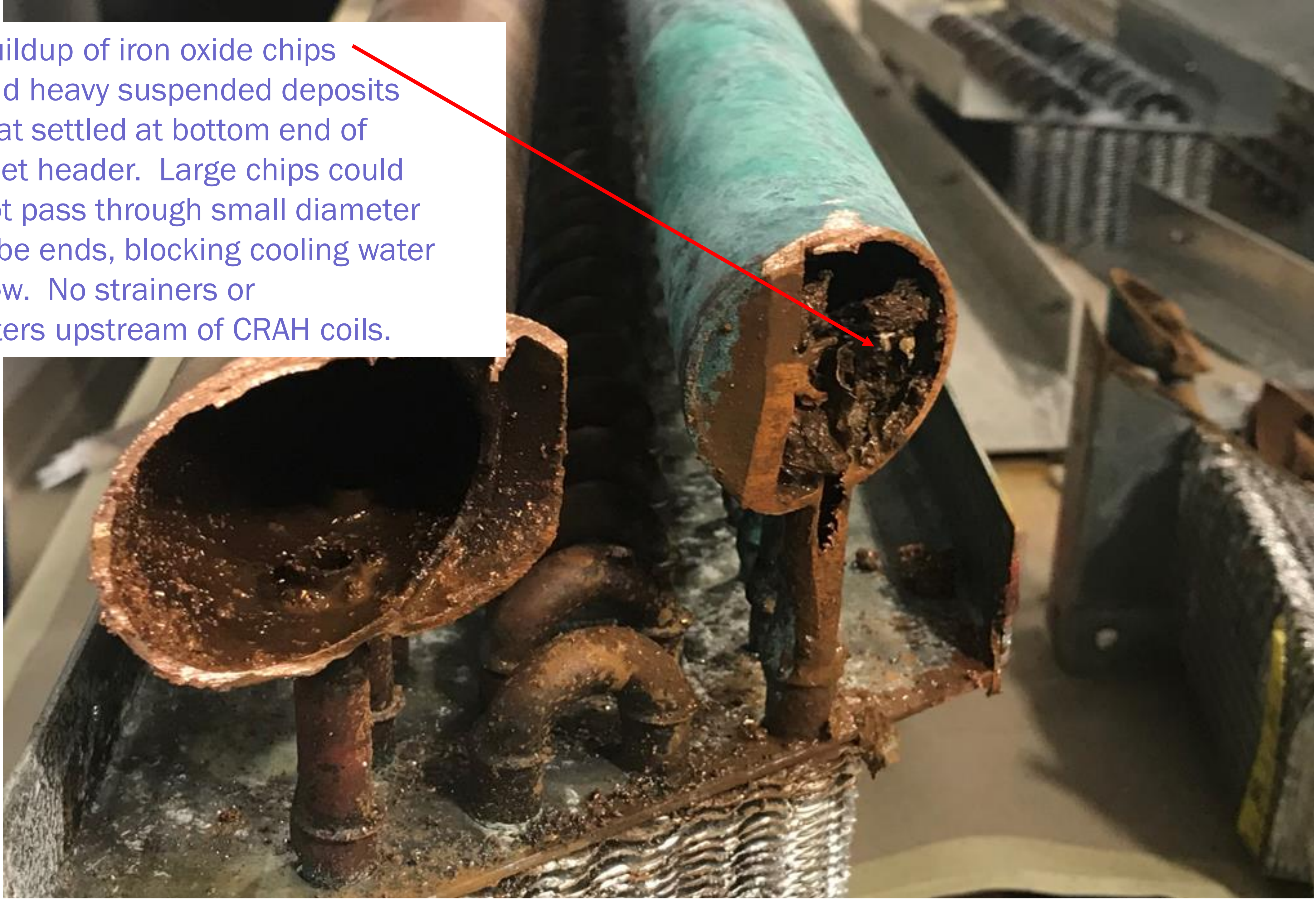
Typical deposits from leaked cooling water containing sodium, silica, and water solids as shown in previous slide.

Deposits on fins contain no cooling water elements. Aluminum oxide and foreign material, possibly from cleaning products.



- Chilled water supply header with inlet port at midpoint.
- Bottom end of header.

Buildup of iron oxide chips and heavy suspended deposits that settled at bottom end of Inlet header. Large chips could not pass through small diameter tube ends, blocking cooling water flow. No strainers or filters upstream of CRAH coils.



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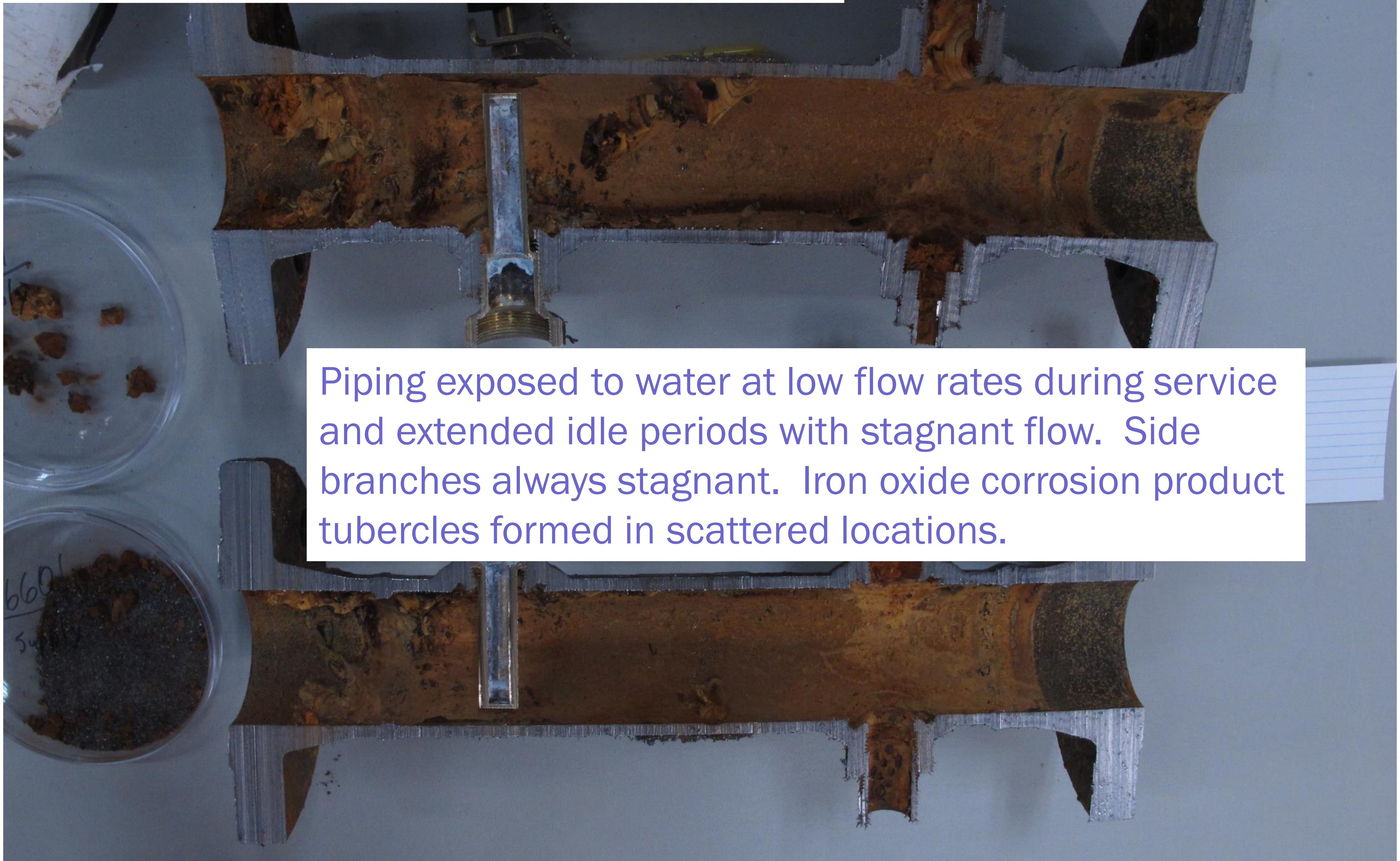
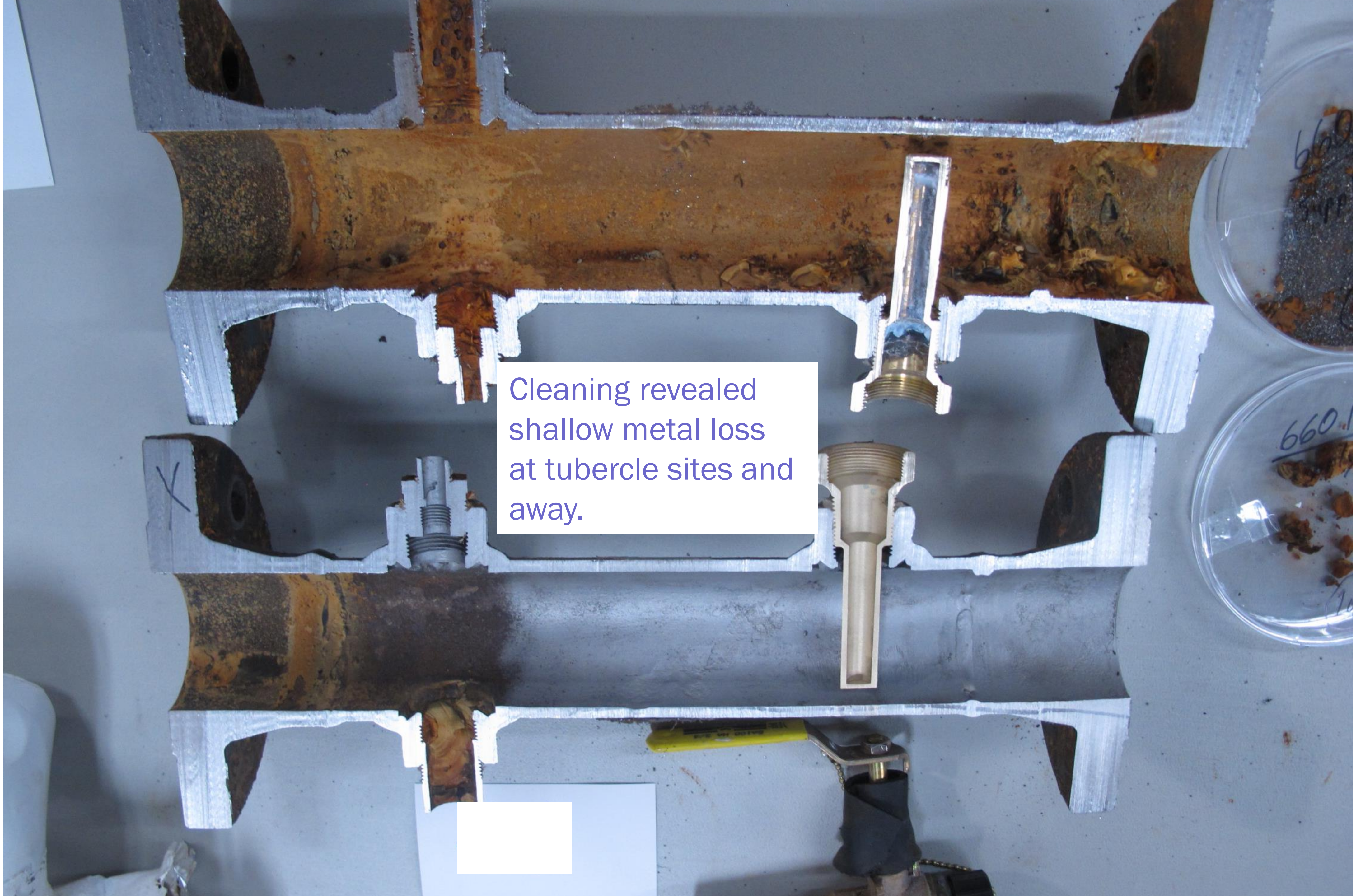
Carbon Steel Chilled Water Supply Spool



Piping exposed to water at low flow rates during service and extended idle periods with stagnant flow. Side branches always stagnant. Iron oxide corrosion product tubercles formed in scattered locations.



Cleaning revealed shallow metal loss at tubercle sites and away.

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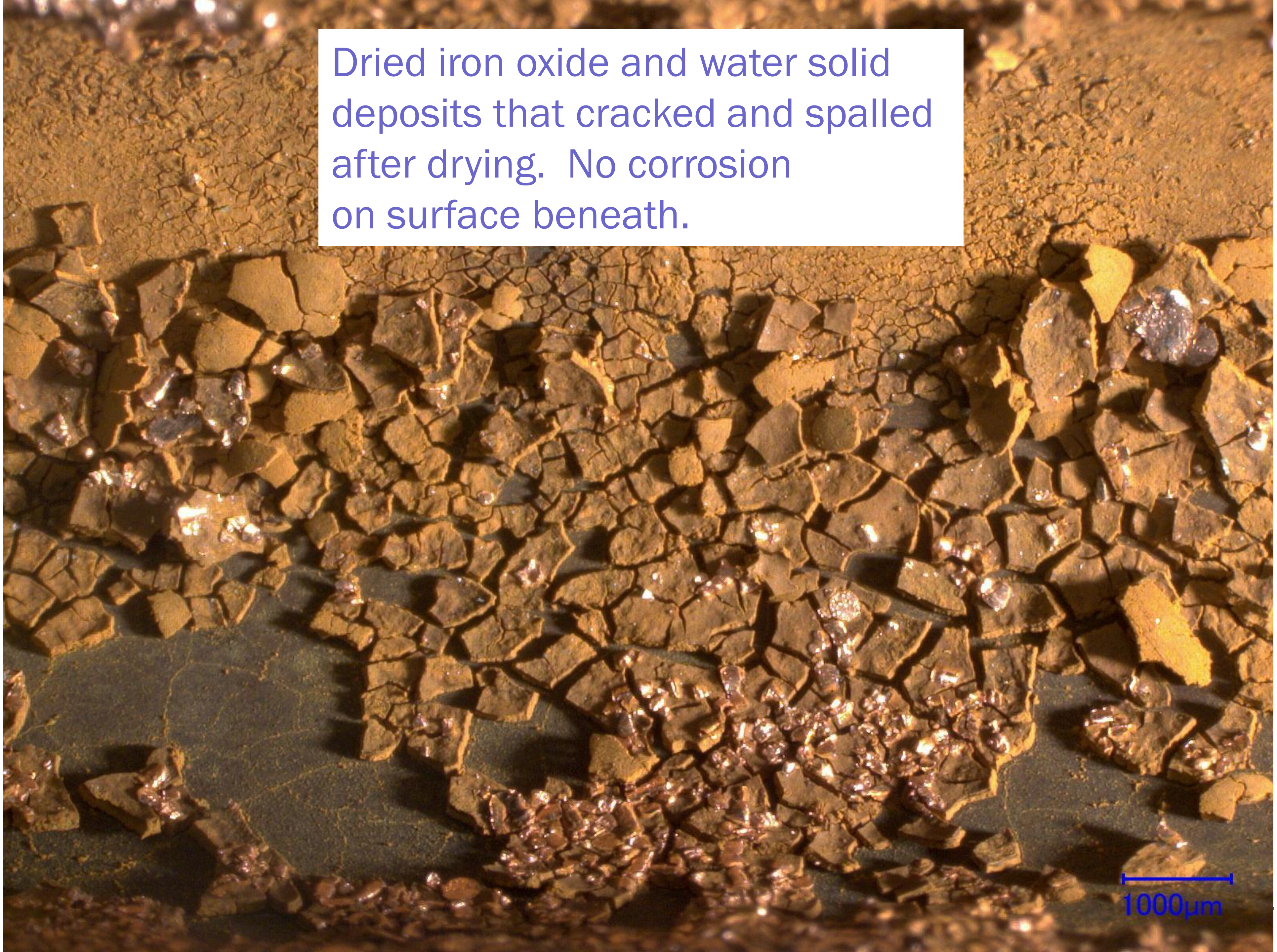
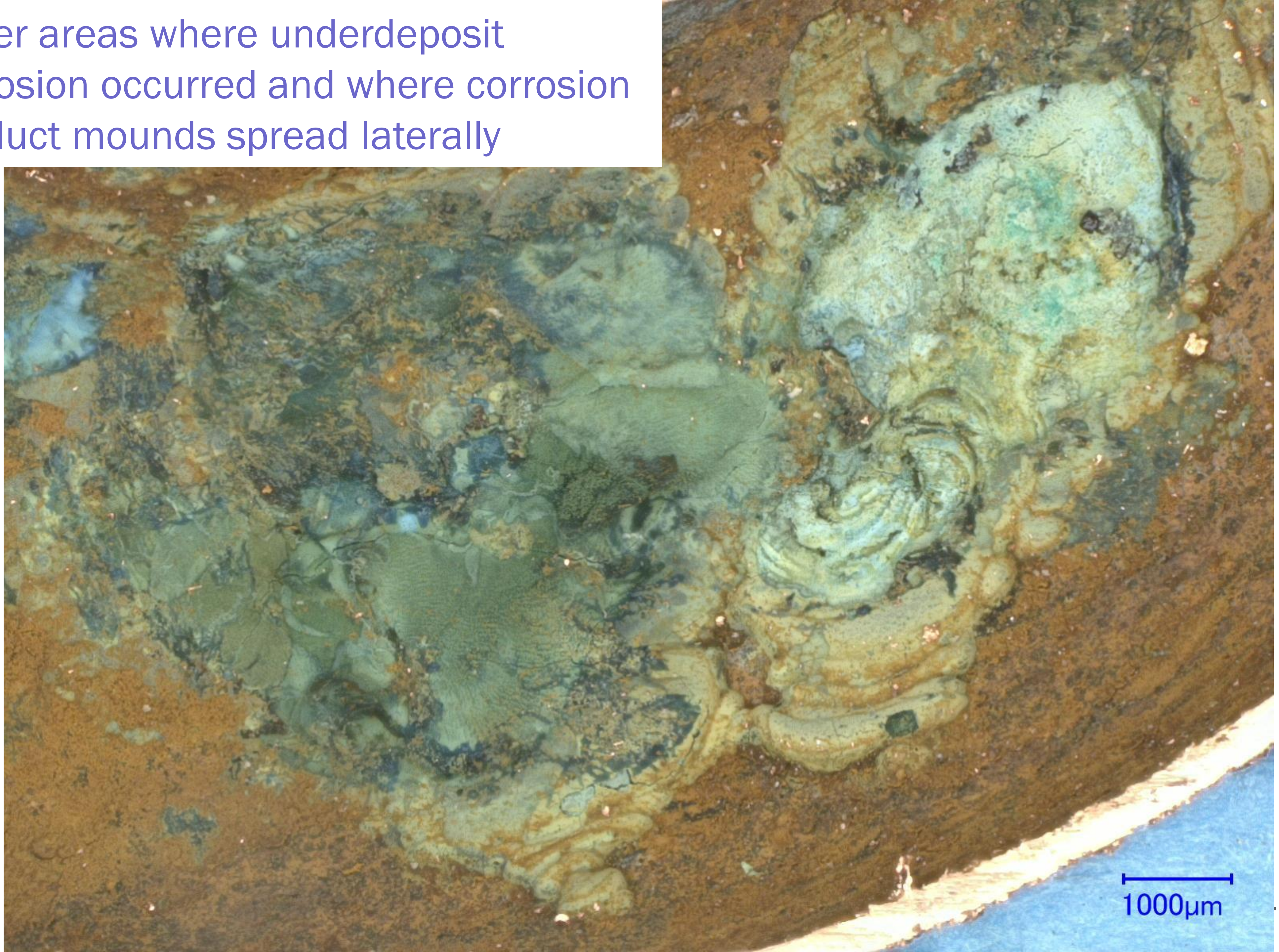
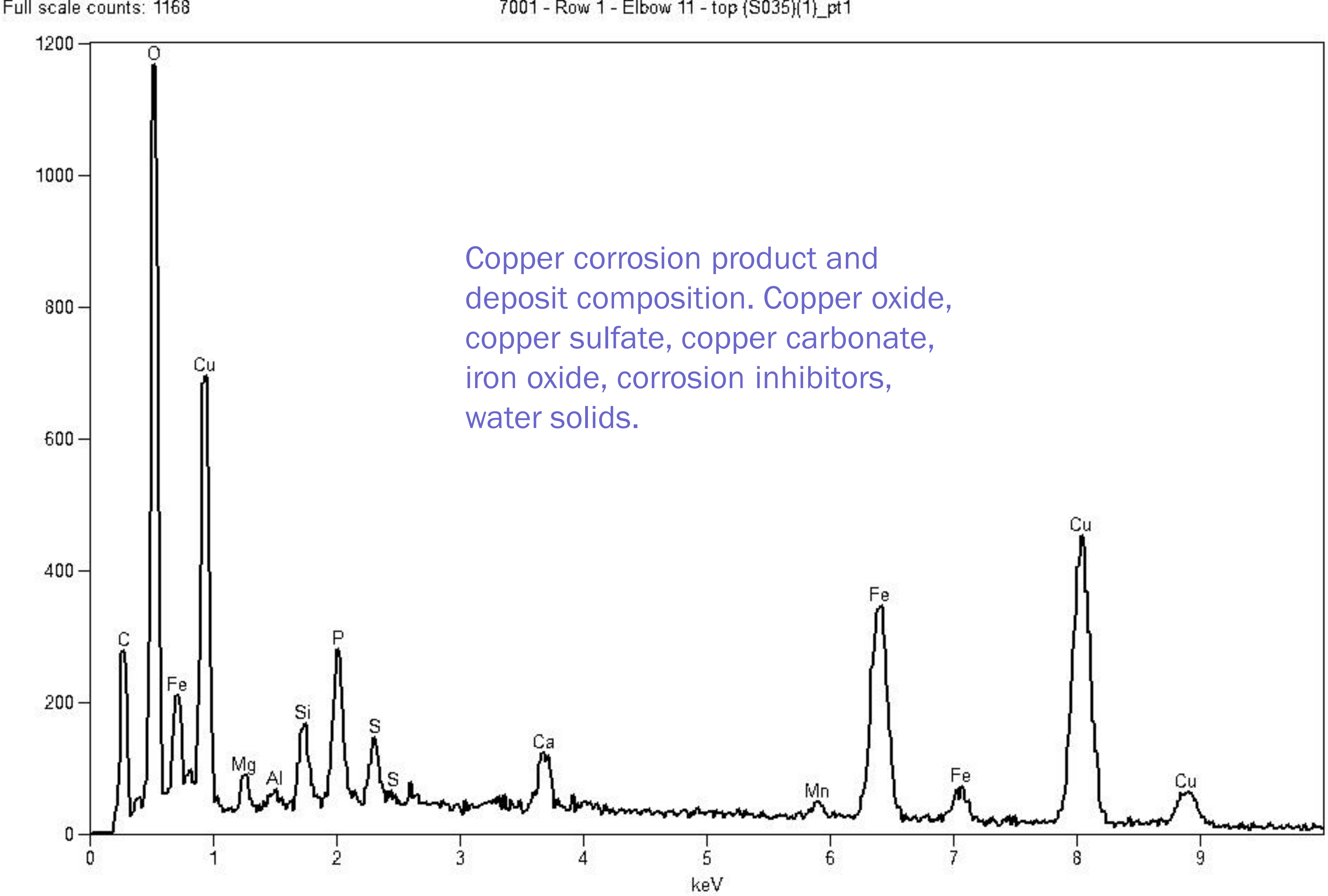
Mostly unattacked internal surface covered with thin, black copper oxide layer. Interrupted in scattered sites by shallow pits that are overlaid by corrosion product layers and mounds.

Dried iron oxide and water solid deposits that cracked and spalled after drying. No corrosion on surface beneath.

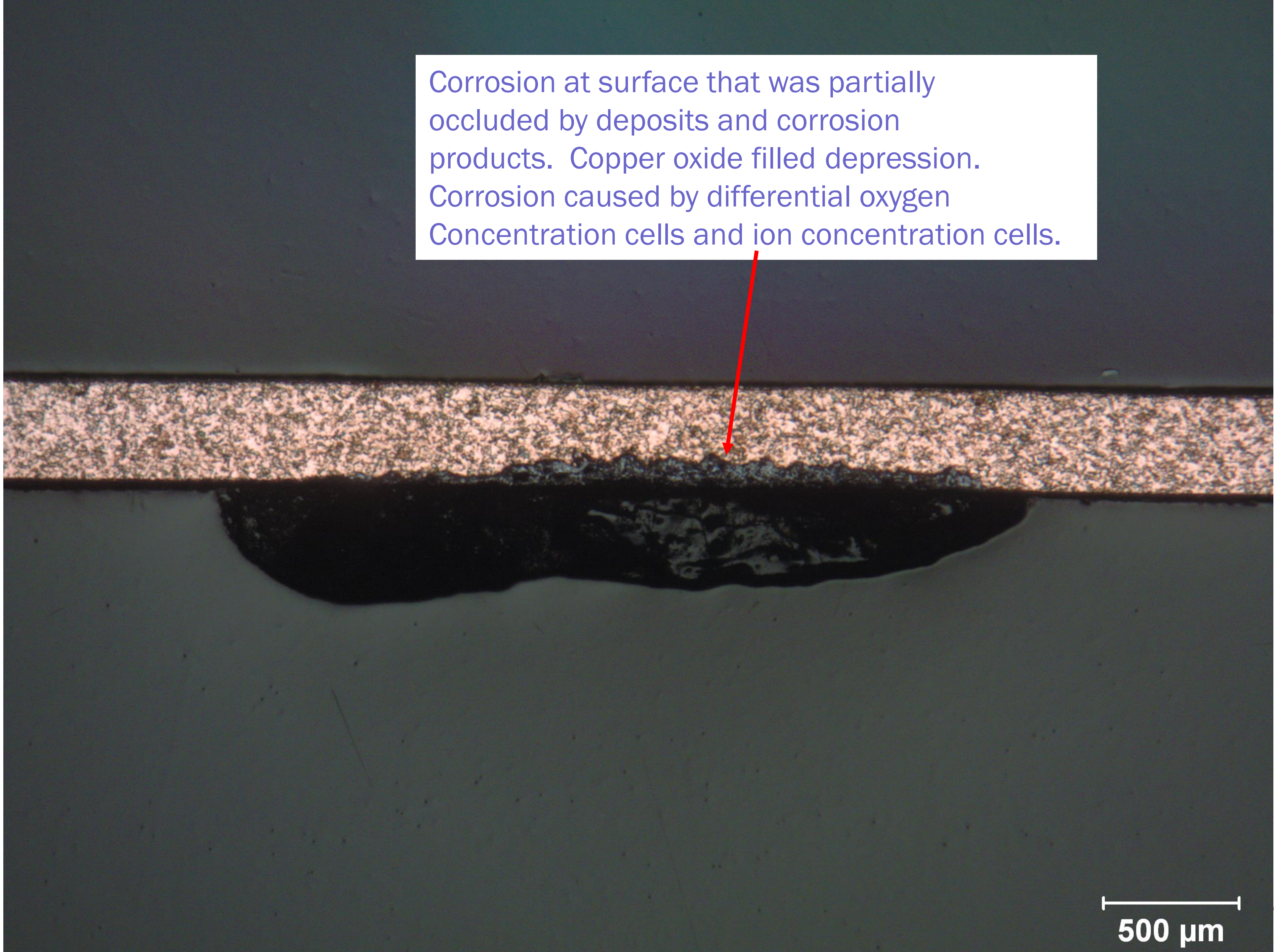


Wider areas where underdeposit corrosion occurred and where corrosion product mounds spread laterally





Copper corrosion product and deposit composition. Copper oxide, copper sulfate, copper carbonate, iron oxide, corrosion inhibitors, water solids.

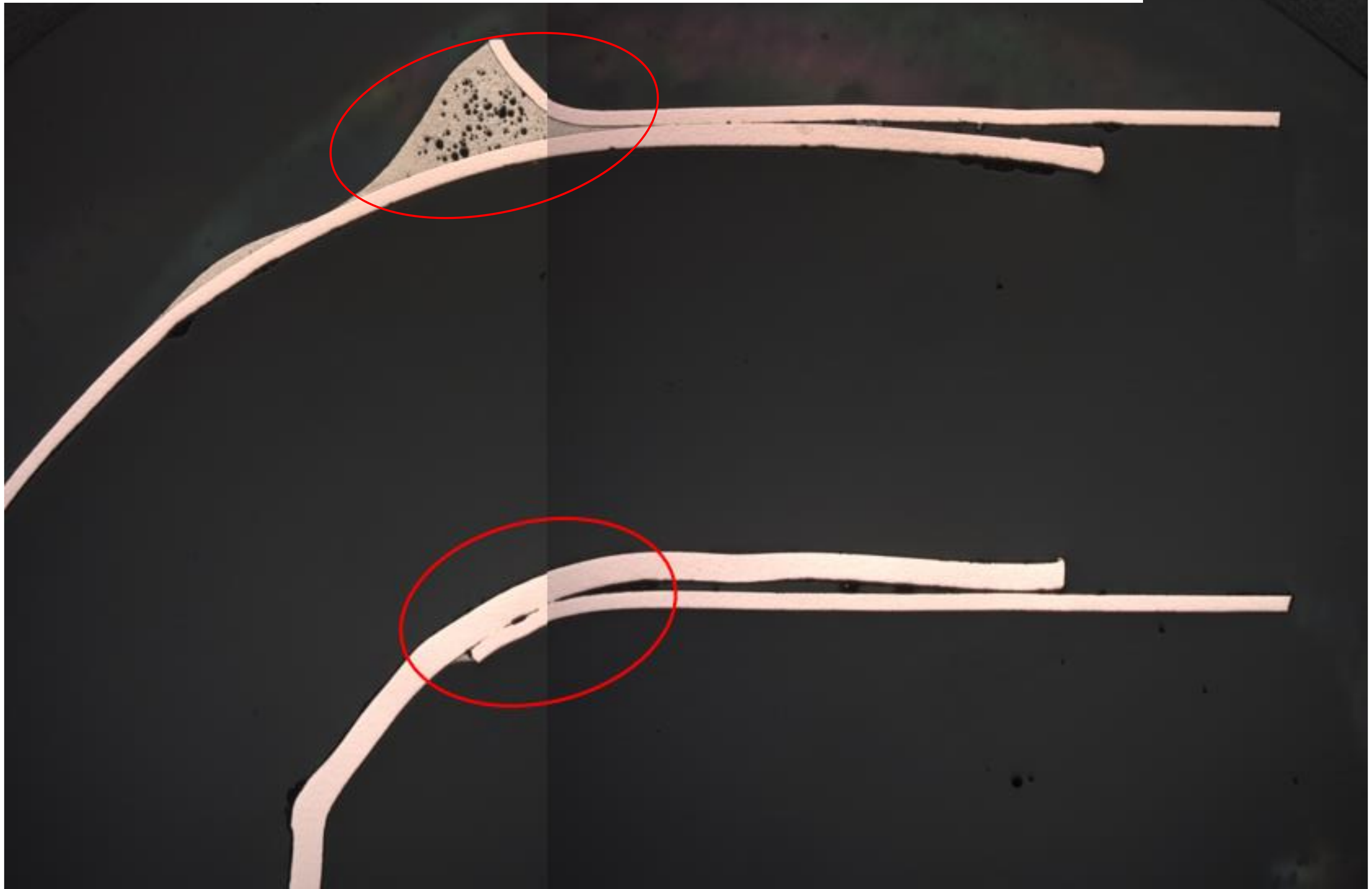

Corrosion at surface that was partially occluded by deposits and corrosion products. Copper oxide filled depression. Corrosion caused by differential oxygen Concentration cells and ion concentration cells.
500 µm

Cross-section of U-bend to CRAH coil tube brazed joints. Portions of joints are not filled, bonded and sealed properly by brazing filler metal.

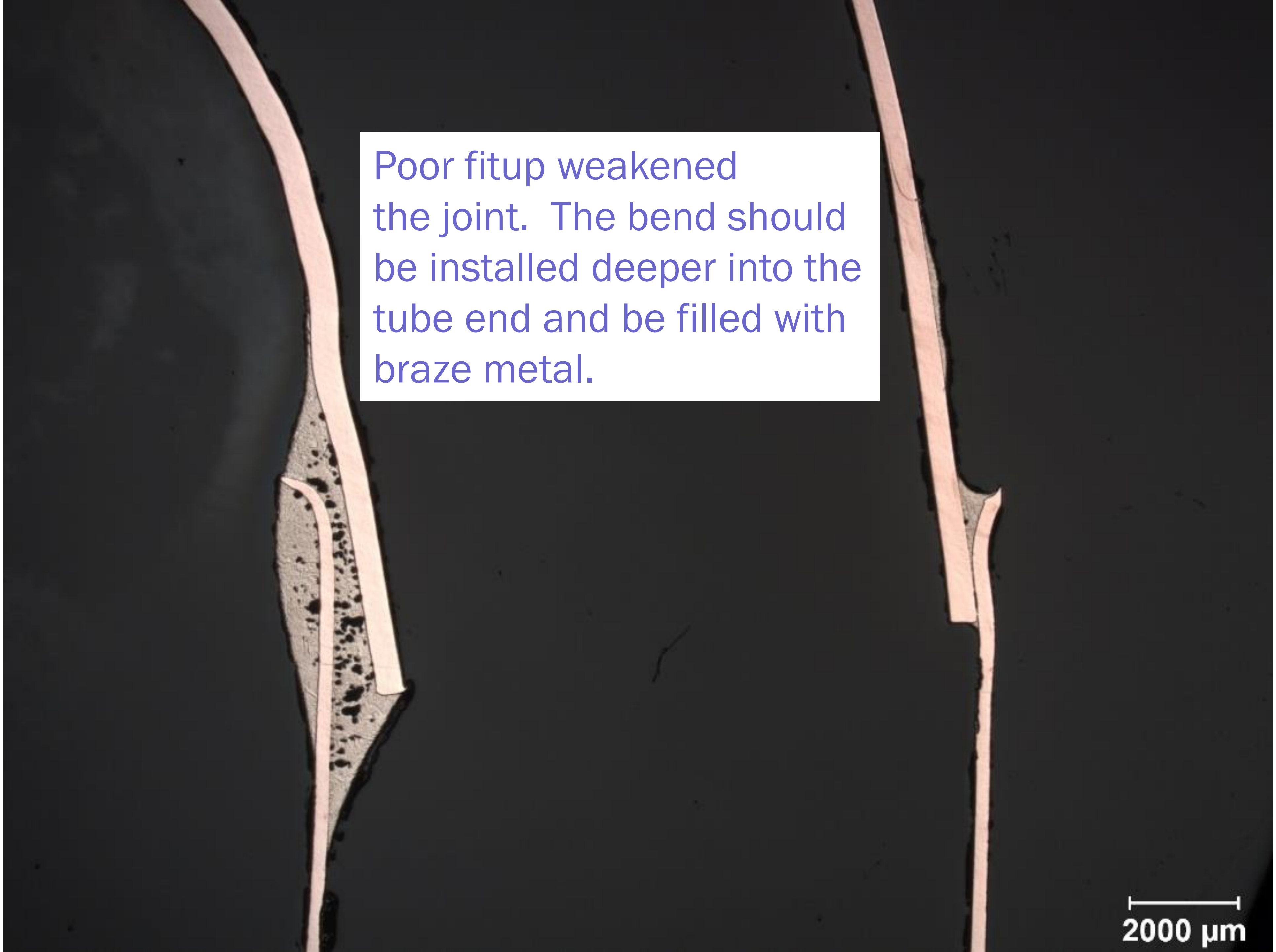
Ideal gap width for brazed joints is 0.001-0.003” to promote wicking of molten filler metal into joint. The gaps here are greater at about 0.010”, which promoted porosity.

Misaligned Tight Joint

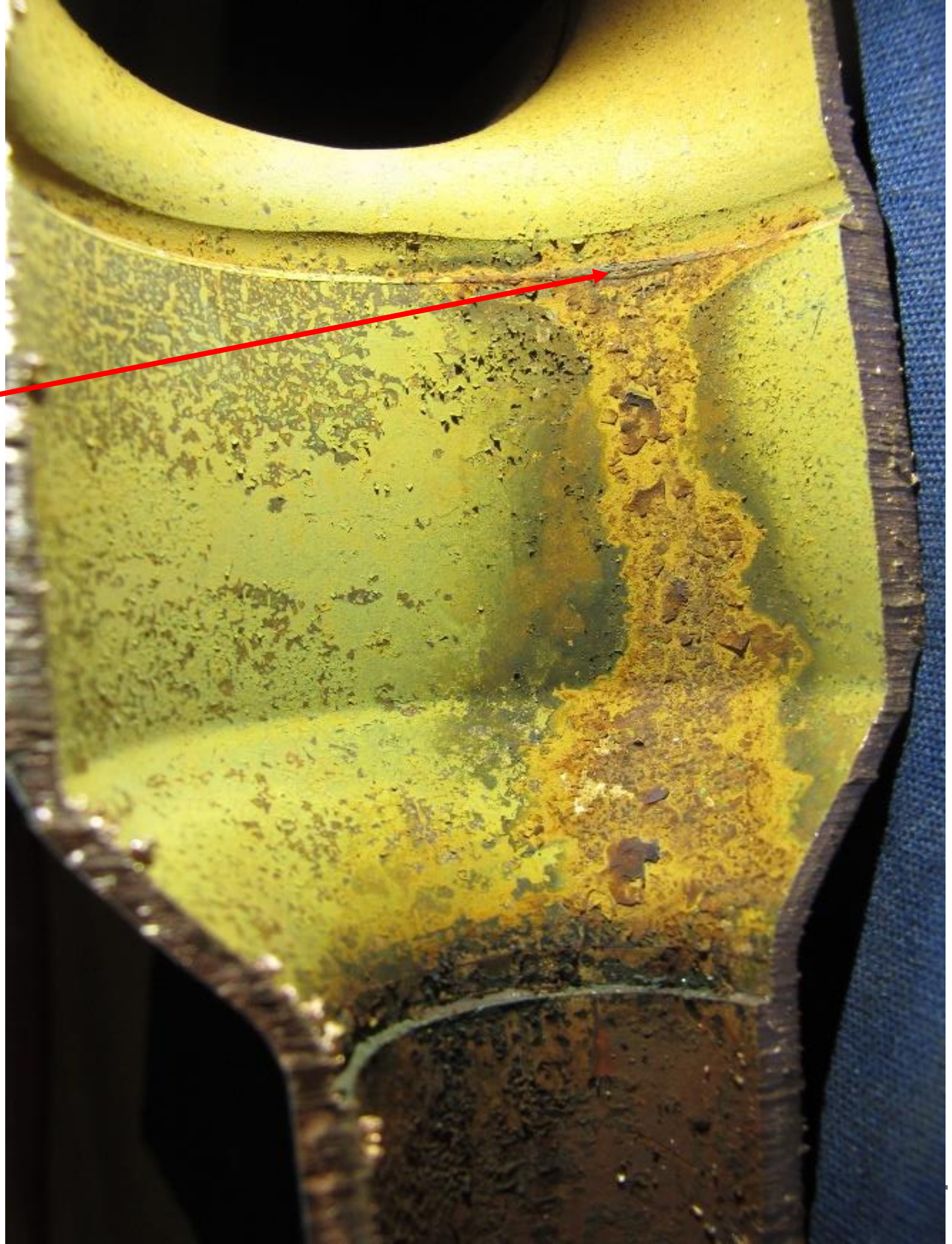
Brazing metal did not penetrate and seal the joint. Braze metal only sealed joint outside of the gap in circled locations.



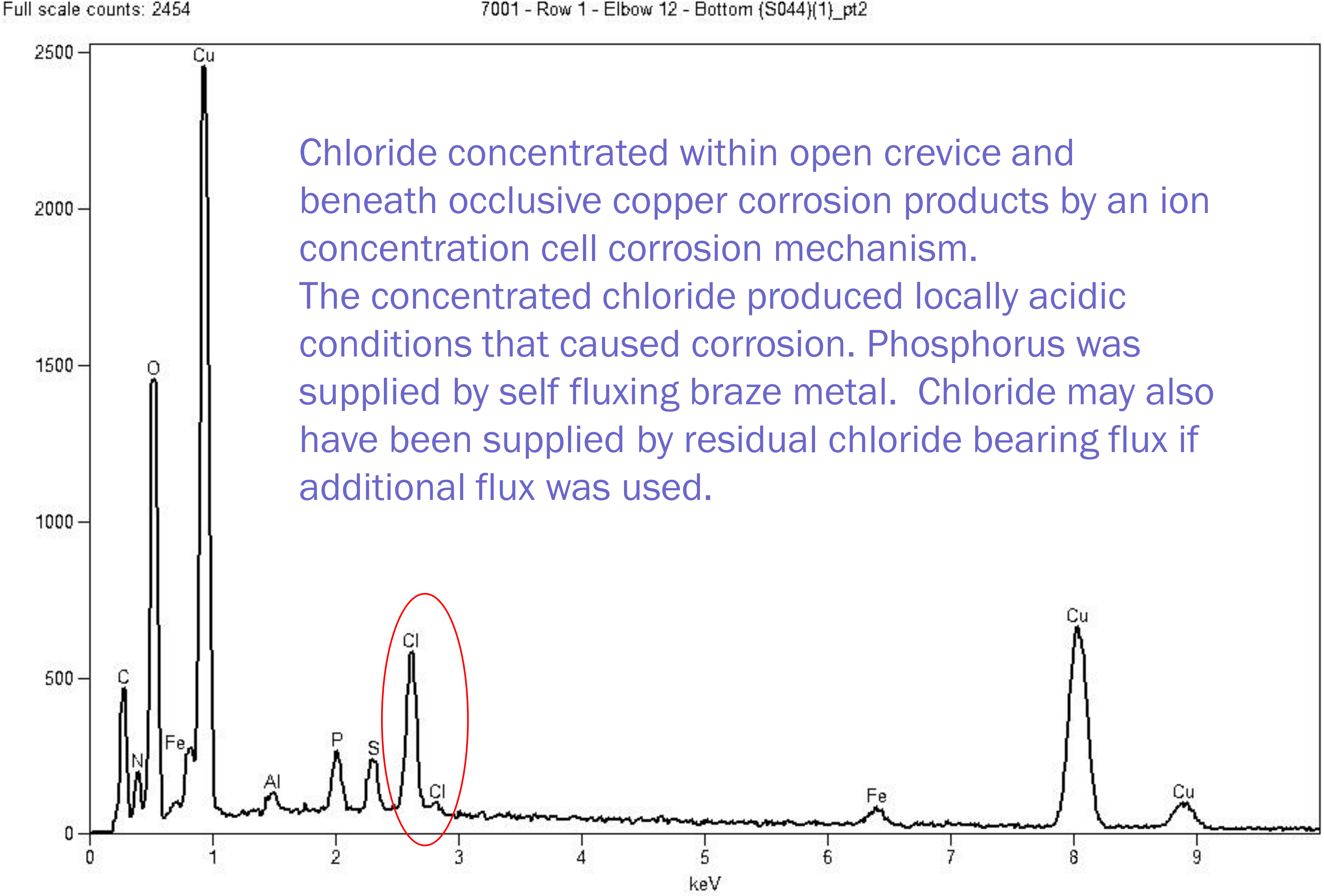
Poor fitup weakened the joint. The bend should be installed deeper into the tube end and be filled with braze metal.



- Vertically oriented brazed header joint where zinc chloride flux dripped downward from joint and corroded surfaces below.
- The header was not flushed immediately following brazing to remove residual corrosive flux.

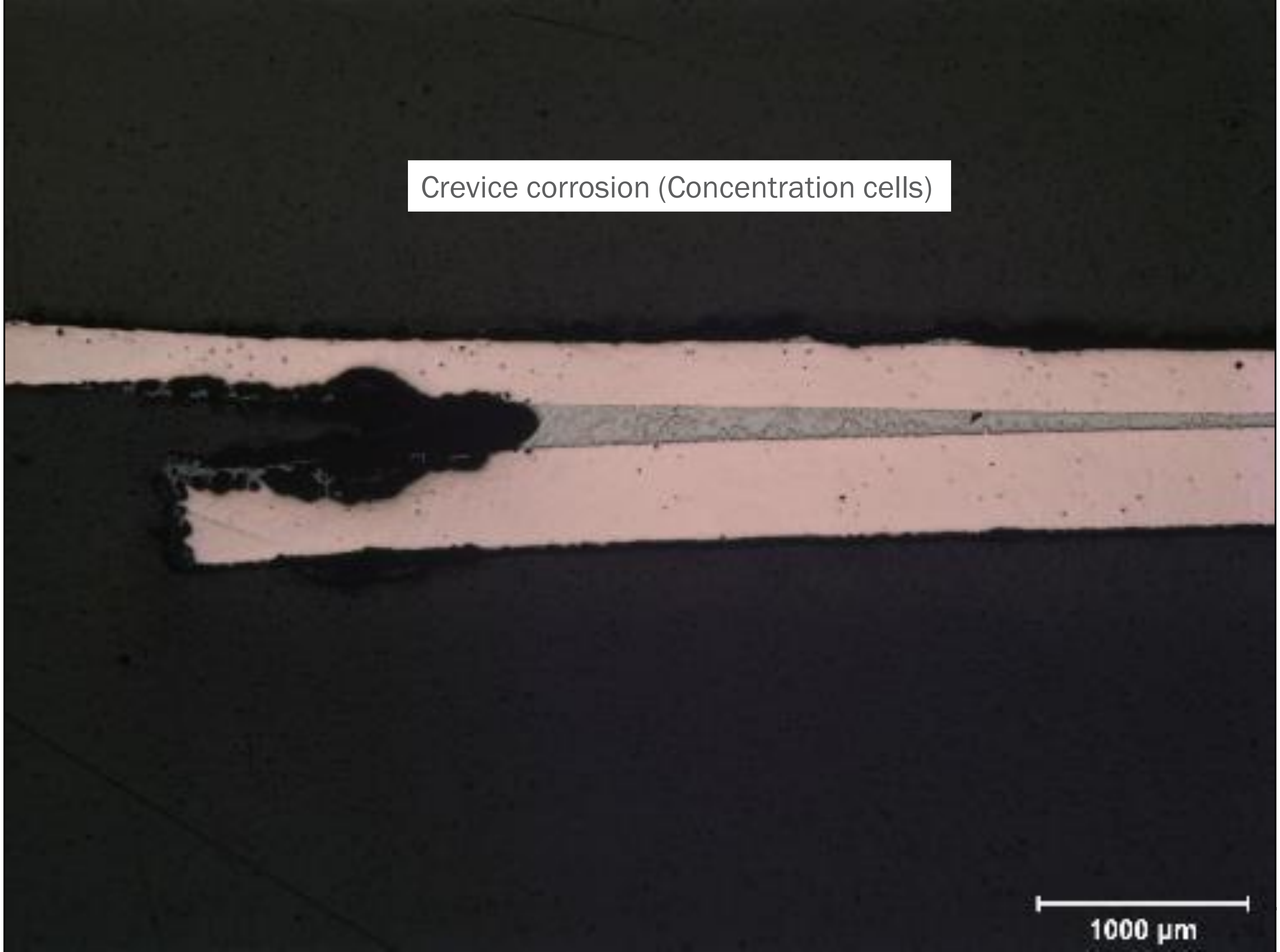



Corrosion within incompletely sealed brazed joint for coil tube to U-bend. Corrosion and corrosion product buildup extends outward from end of joint.
1000μm



Chloride concentrated within open crevice and beneath occlusive copper corrosion products by an ion concentration cell corrosion mechanism.

The concentrated chloride produced locally acidic conditions that caused corrosion. Phosphorus was supplied by self fluxing braze metal. Chloride may also have been supplied by residual chloride bearing flux if additional flux was used.


Crevice corrosion (Concentration cells)
1000 µm

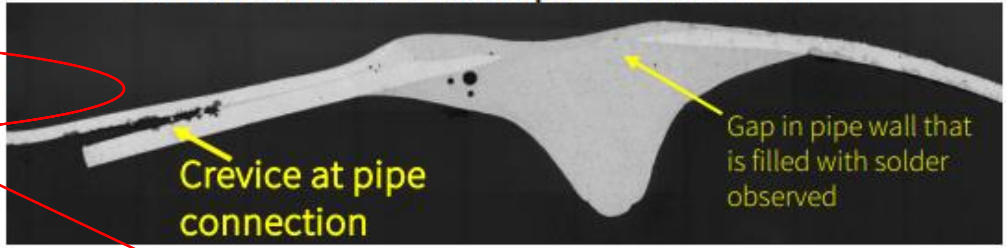
te.

Similar Case from a Third Party Lab

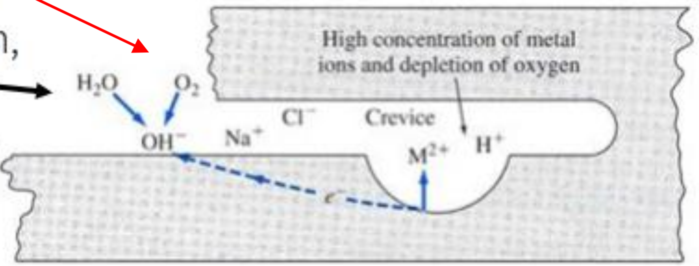
- The accelerated corrosion in the unit analyzed was likely caused by crevices at the straight pipe / U-bend connections in conjunction with the presence of corrosive species in the environment.
- This conclusion was based on the following factors:
  - On the interior of the pipes, the corrosion was concentrated around the straight pipe / U-bend connections.
  - Crevices were observed at these connections.
  - Chlorine and sulfur detected by EDS around the crevices suggests that corrosive ions in the chilled water migrated into the crevices.
  - Crevice corrosion was likely initiated and promoted by detrimental changes in the local chemistry within the crevice, resulting in the accelerated rate of corrosion.
- Crevices can form at the pipe connections due to solder not filling the overlap region. A lack of solder fill may result from:
  - Insufficient or incomplete solder
  - Pipe diameter gap being too large or too small
  - Pipe overlap region being too long

Corrosion on Interior of Pipe

Observed Crevice at Pipe Connection



Crevices cause local stagnation, reduced inhibitor, and a buildup of ion species.




FLOW

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Copper and mild steel corrosion rates were always excellent. Coupon testing must be conducted at minimum flow rate of 1.5 ft/s as mandated by ASTM, with no flow variation.

Corrosion Coupon Analysis — Corrosion Rate (Mils per year)

Date	*Location*	*Days*	*Copper*	*Mild Steel*	*70 30 Cu:Ni*
5/11/2009	CHW	335	<0.1	1.9	
12/22/2014	CHW	84	0.1	0.3	
4/17/2015	CHW	86	0.1		
4/17/2015	CHW	86		0.4	
4/17/2015	CHW	86	0.1	0.6	
6/29/2015	CHW	217	<0.1	0.4	
6/29/2015	CHW	84	0.1		
6/29/2015	CHW	217		0.5	
6/29/2015	CHW	84	<0.1	0.8	
6/29/2015	CHW	84	0.1		
6/29/2015	CHW	140	0.1	0.6	
10/6/2015	CHW	91	0.1	0.7	
10/6/2015	CHW	91	0.1	0.7	
12/28/2015	CHW	175	<0.1	0.6	
12/28/2015	CHW	115	<0.1	0.2	
12/28/2015	CHW	175	<0.1	0.4	
12/28/2015	CHW	115	<0.1	0.2	
2/19/2016	CHW	86	0.1	0.9	
3/18/2016	CHW	91	<0.1	0.7	
3/18/2016	CHW	91	<0.1	0.4	
3/18/2016	CHW	91	<0.1	0.5	
4/22/2016	CHW	28			<0.1
6/21/2016	CHW	189	<0.1	0.5	
6/21/2016	CHW	70			<0.1
6/21/2016	CHW	98			<0.1

Conclusion

- Low flow through system (0.5 ft/s) promoted settling of suspended solids and corrosion. Low flow reduced replenishment and effectiveness of inhibitors. Minimum flow rate recommended >3 ft/s.
- Stagnant flow, long idle periods promoted corrosion throughout the system
- ASTM prohibits coupon testing when flow rates are less than 1.5 ft/s and must not be variable. Testing under low flow and variable flow conditions will produce questionable results.
- TES tank periodic cleaning not conducted. Filtration required to prevent contamination of the coil tubing.
- Thin, weak, copper tubing was susceptible to fatigue cracking by cyclic applied stresses due to poor design of the coil (unsupported headers, etc.).
- External surface metal loss caused by fretting due to contact with tube supports.
- Poorly constructed and defective brazed joints are weak and susceptible to crevice corrosion.

Other Topic of Interest
Design of Cold Plate

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- Very tight fin spacing for cold plate (about 0.005” – or 2 sheets of paper)
- Acts as filter to trap even small suspended solids.

One side of each fin is rough due to manufacturing, may contribute to solids entrapment.