# Tin Whisker Observations on Tin-Coated Copper Bus Bar Obtained from "A Large Paper Mill in Sweden"

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# Background

- Since 1997 a large paper mill in Sweden has experienced three major arcing events (1997, 2000, 2009) involving tin-plated bus bars in power distribution cabinets. In the first two events, the root cause of the arcing was not determined.
  - Applied Voltage = 500 Volts AC between adjacent bus bars
  - Distance between bus bars ~20-mm

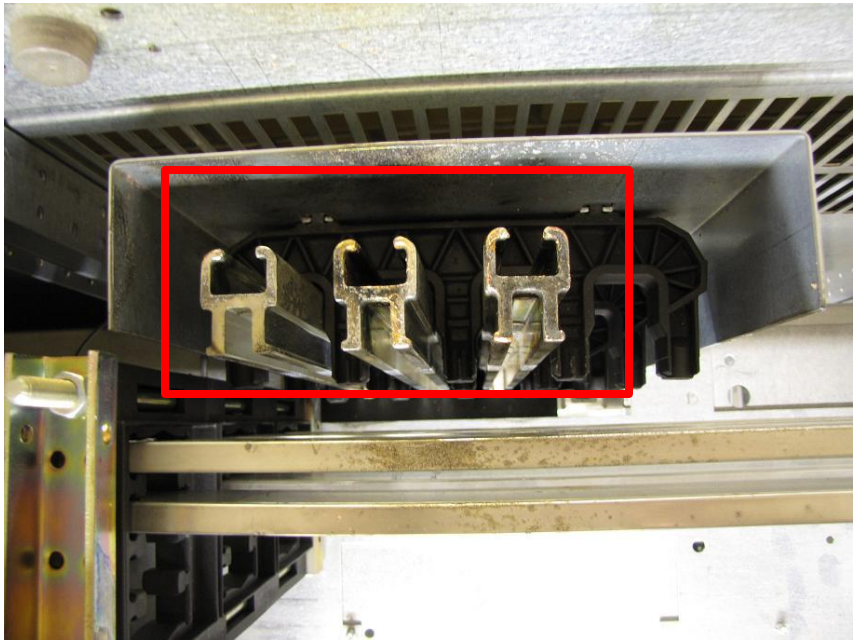
- After the third arcing event (2009), the paper mill representative, Anders Johansson, contacted Jay Brusse and Henning Leidecker (NASA Goddard Space Flight Center) to share images and to ask about the potential for metal whiskers to produce metal vapor arcs.
  - Images of bus bars showed features suspected to be metal whisker formations
  - NASA offered to perform materials analysis on a segment of one bus bar provided by the paper mill
  - Original manufacturing date of bus bar was reported to be circa 1988

# Images from 2009 Arcing Event @ Paper Mill in Sweden

Photos Provided by Anders Johansson

**Bottom of Cabinet**

**Top Cabinet**

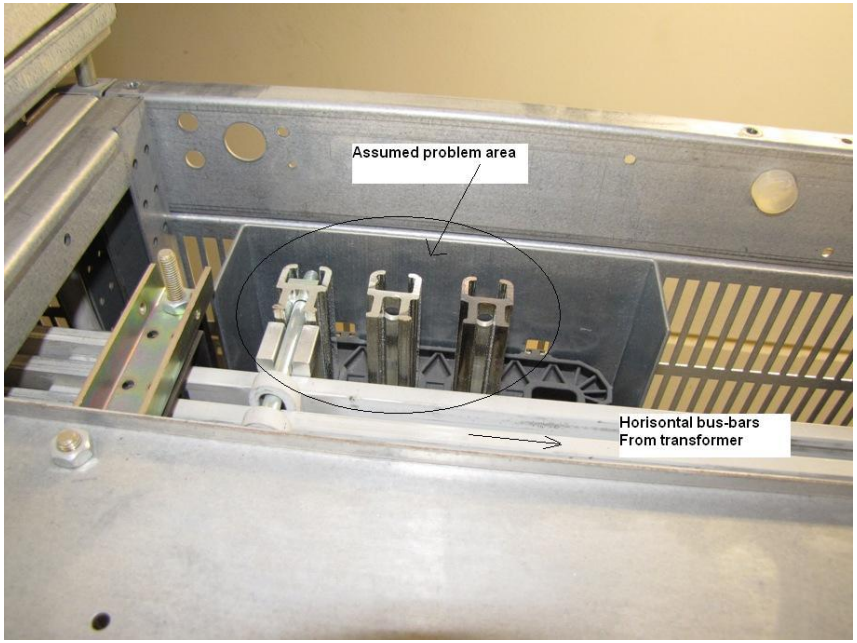


# Images from 2009 Arcing Event @ Paper Mill in Sweden

Photos Taken by Anders Johansson

**Cabinet stripped from feeder groups. Vertical bus bars visible**


**Top of cabinet removed. Top of vertical bus bars visible.**

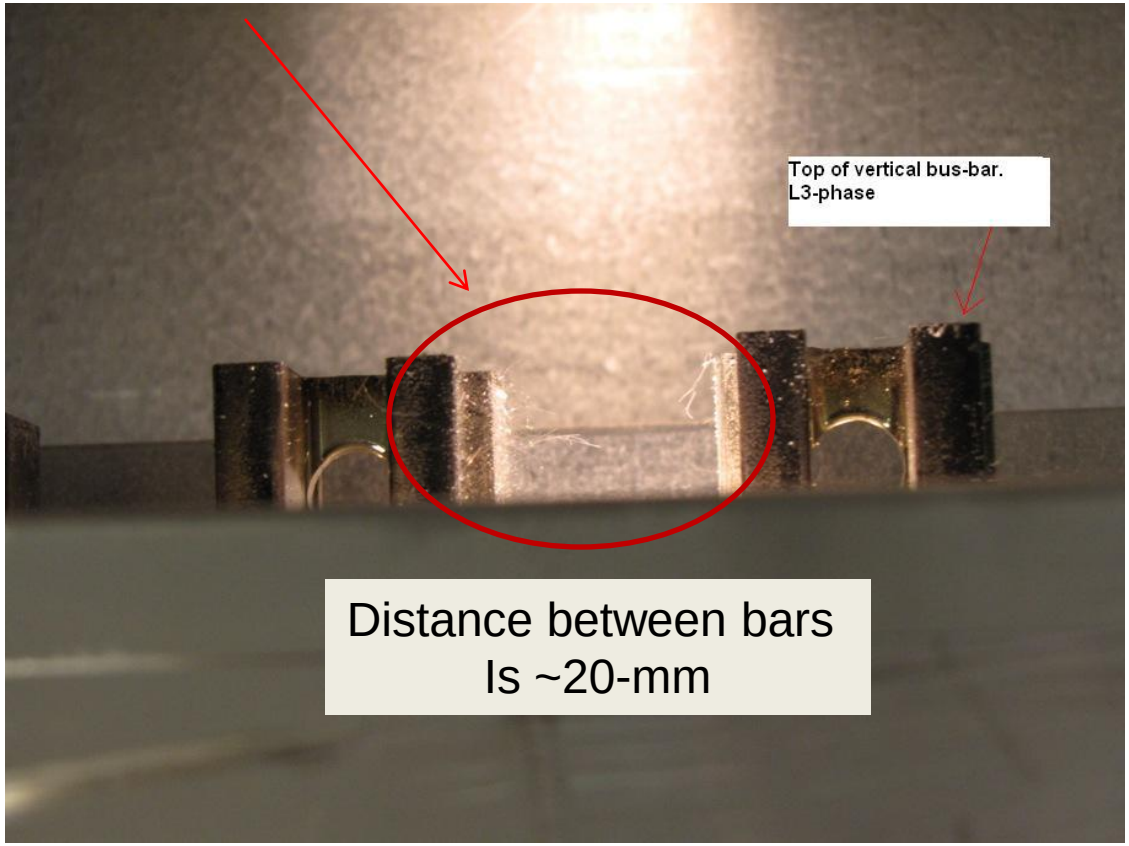


# Images from 2009 Arcing Event @ Paper Mill in Sweden

Photos Taken by Anders Johansson

**Top of vertical bus bars.**

**Suspicious filaments visible in gap between bars**



# Image from 2000 Arcing Event @ Paper Mill in Sweden

Photos Provided by Anders Johansson

# Images from 1997 Arcing Event @ Paper Mill in Sweden

Photos Provided by Anders Johansson

**Cabinet Disassembled**

**After Arcing**

**Arcing Damage**

# Analysis of Bus Bar

- Lyudmyla Panashchenko (University of Maryland) provided lab services for the analysis of the Bus Bar provided to NASA Goddard
- Analyses included:
  - Determination of material composition of rail and surface finish
    - X-ray Fluorescence (XRF) Spectroscopy
    - Energy Dispersive X-ray Spectroscopy (EDS)
  - Measurement of surface finish thickness
    - XRF
  - Confirmation of tin whisker growths from the surface finish
    - Optical Microscopy
    - Scanning Electron Microscopy (SEM) + EDS

# Bus Bar Sample Cut by Anders Johansson and Sent to NASA for Analysis Herein

# NASA Findings

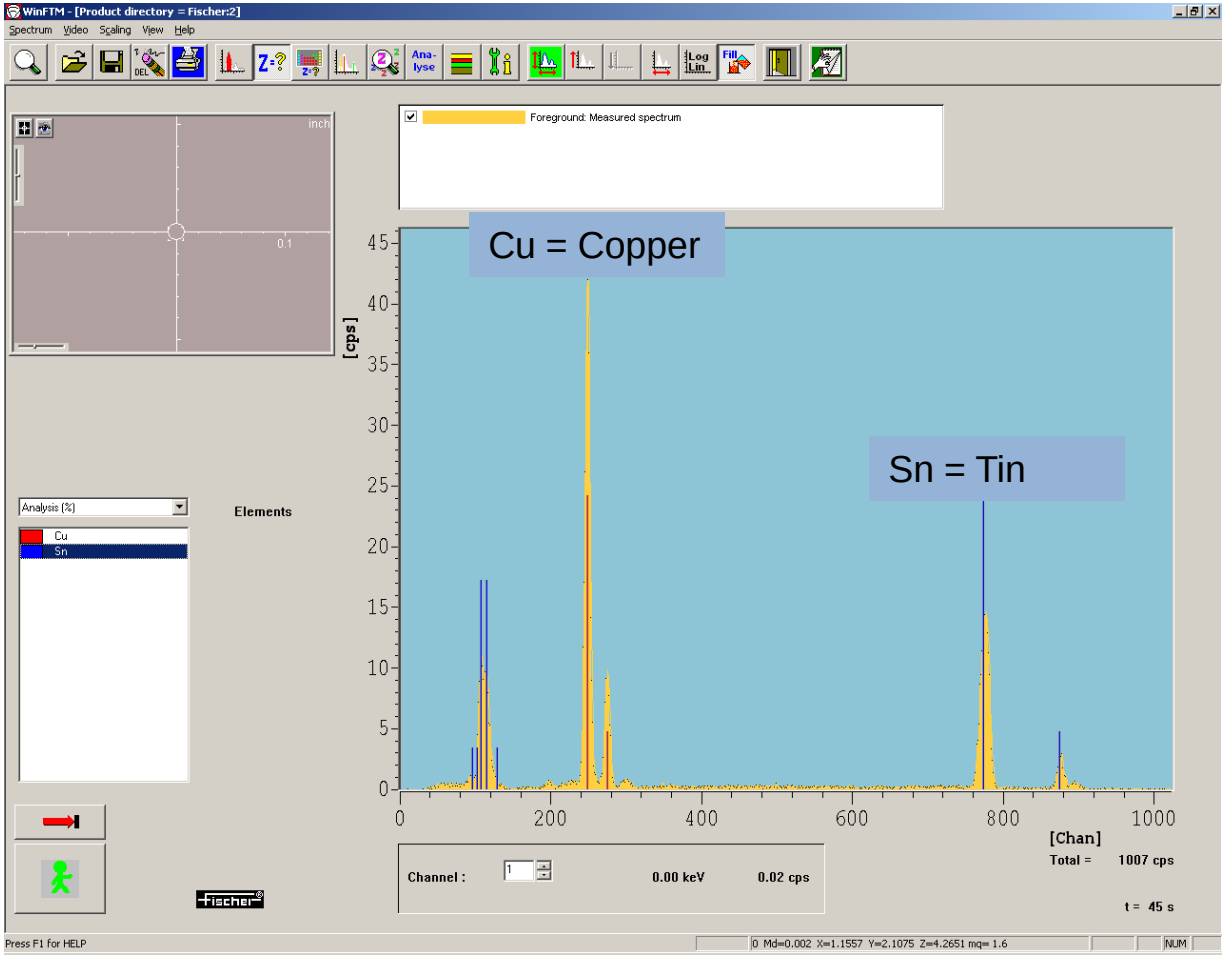
- Bus bar base metal = Copper (Cu)
- Surface Finish = Tin (Sn)
- Surface Finish Thickness = variable along length of bus bar
  - Range from 1.26 - 26.2 microns in areas examined
  - Thinner Sn coating is located at the uncut end of the bus bar (by XRF)
- **TIN WHISKERS**:
  - Extensive tin whisker formations were confirmed by these inspections
  - Many whiskers are longer than 1-mm, some whiskers >3-mm.
  - Tin whisker density (# per area) is non-uniform
    - Very high density nearest the uncut ends of the bus bar (where plating is thinner)
    - Very low density near the cut end of bus bar
- Localized darkening, blistering and flaking of the tin surface finish was observed
  - Most noticeable in region with highest tin whisker density.
  - Discoloration looks like charring of the surface , but cause has not been determined
    - Might occur during localized heating of the bus bar (e.g., possible arcing event), but supplier does not believe sample provided for analysis had been involved in any arcing events
    - EDS of this region shows only Sn and O (i.e., no C). May be very thick tin-oxide layer.

# X-Ray Fluorescence Spectroscopy (XRF)

XRF is a non-destructive method for measuring both the thickness and the elemental composition of thin surface finishes and the underlying base material.

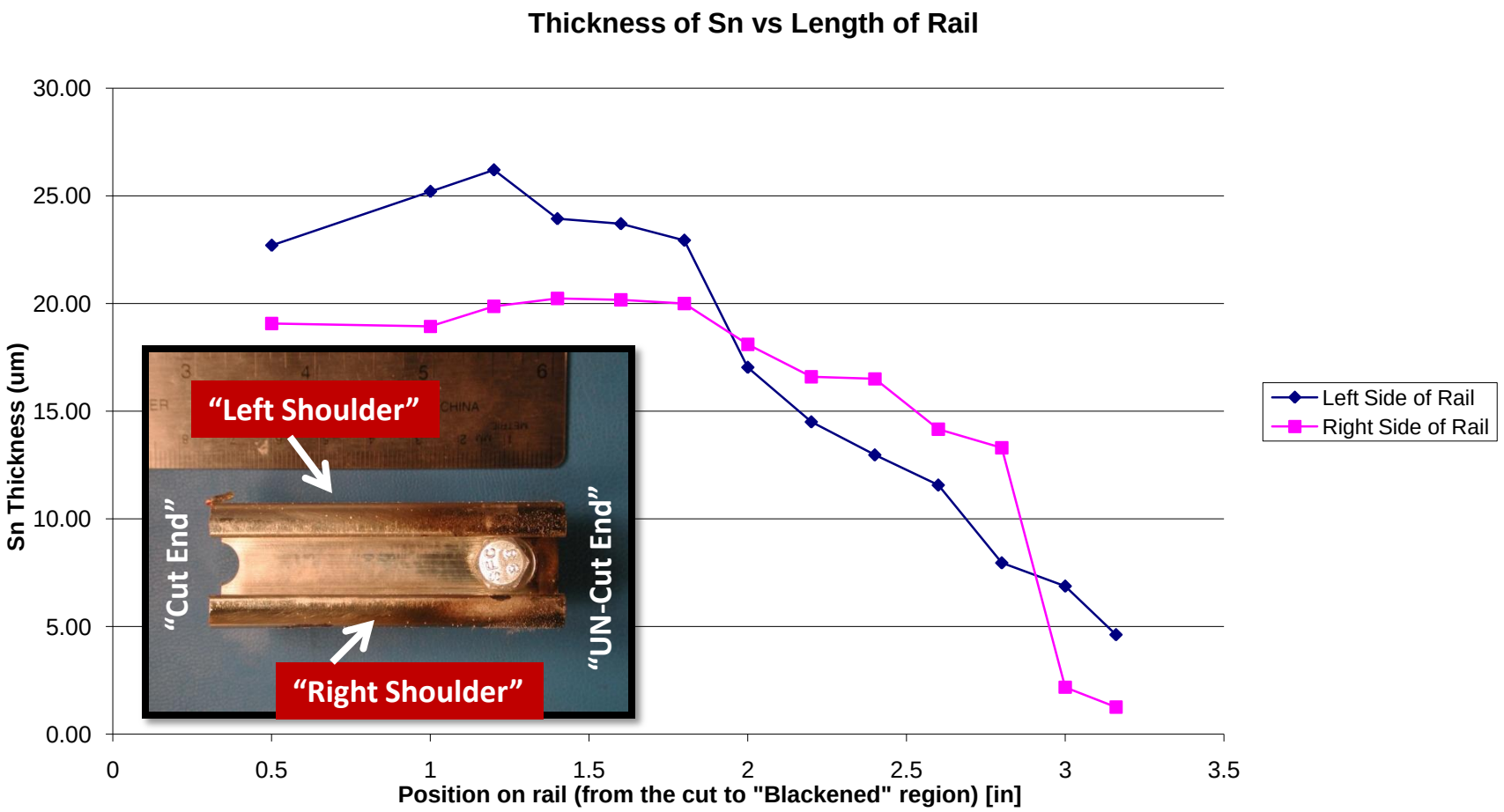
Analysis by Lyudmyla Panashchenko

# XRF Spectrum of Bus Bar Confirms Tin Over Copper Construction



# Tin thickness vs. Position on Shoulders of Rail

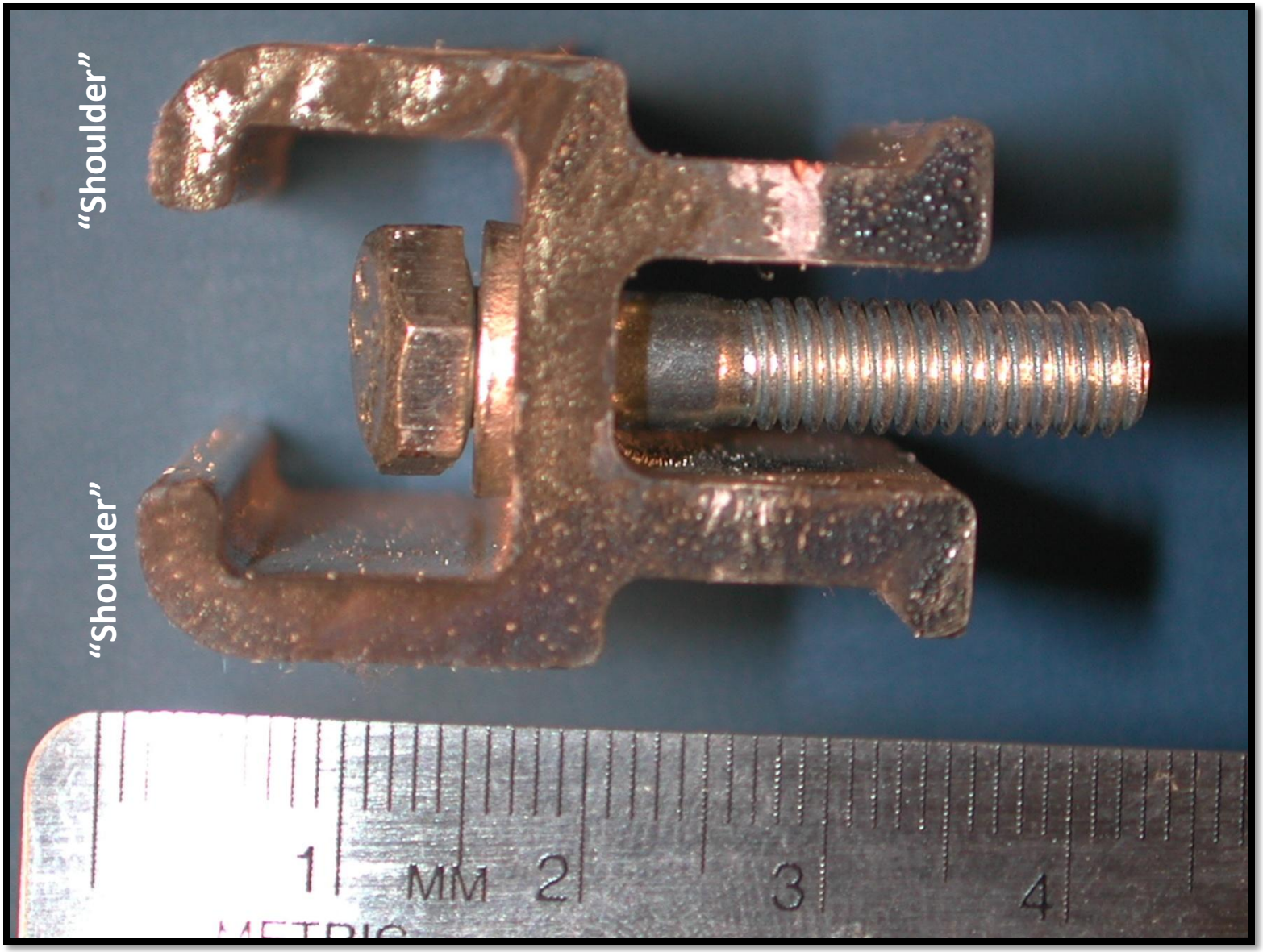
(Measured by X-Ray Fluorescence)

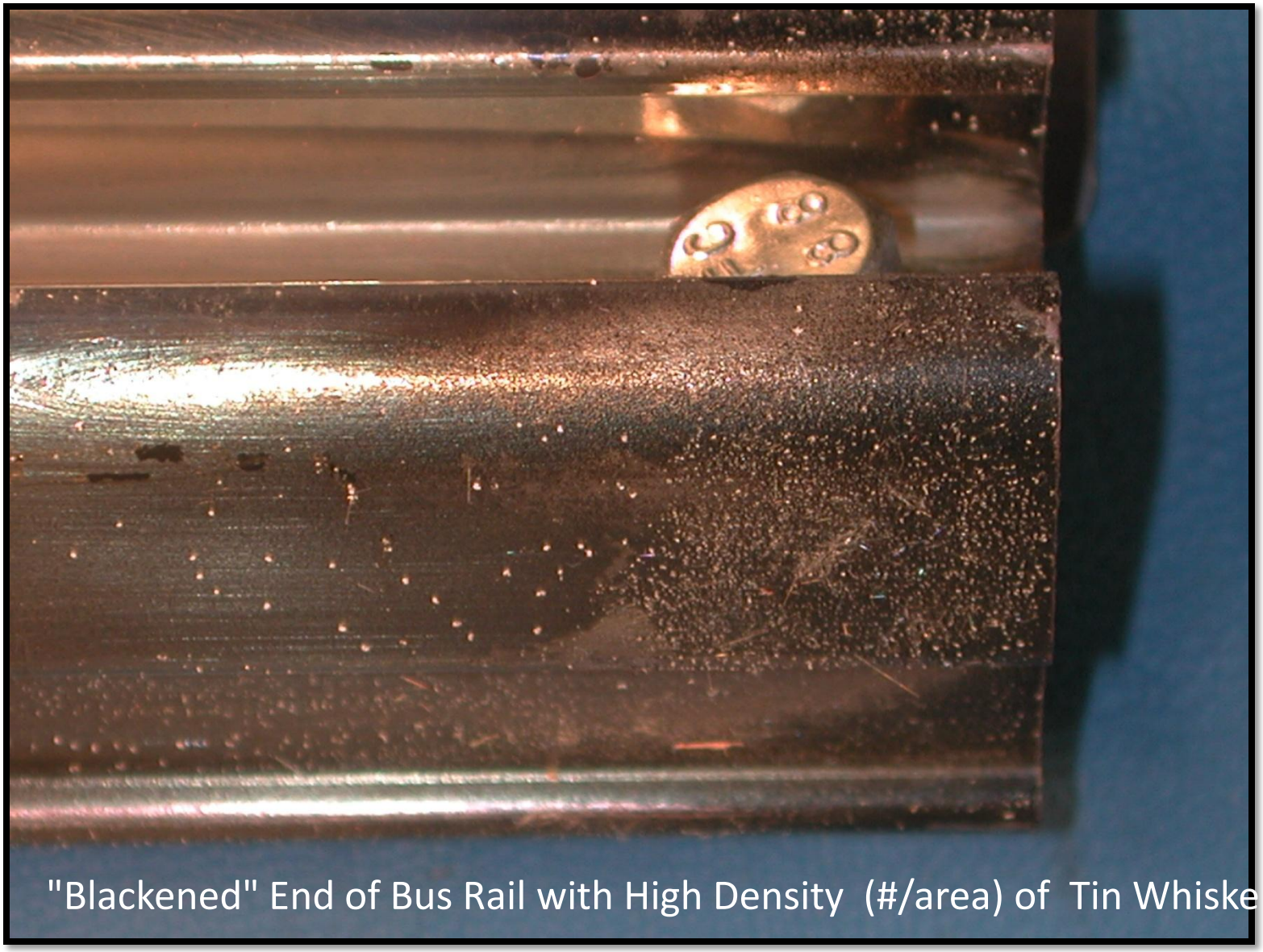


# Optical Microscopy

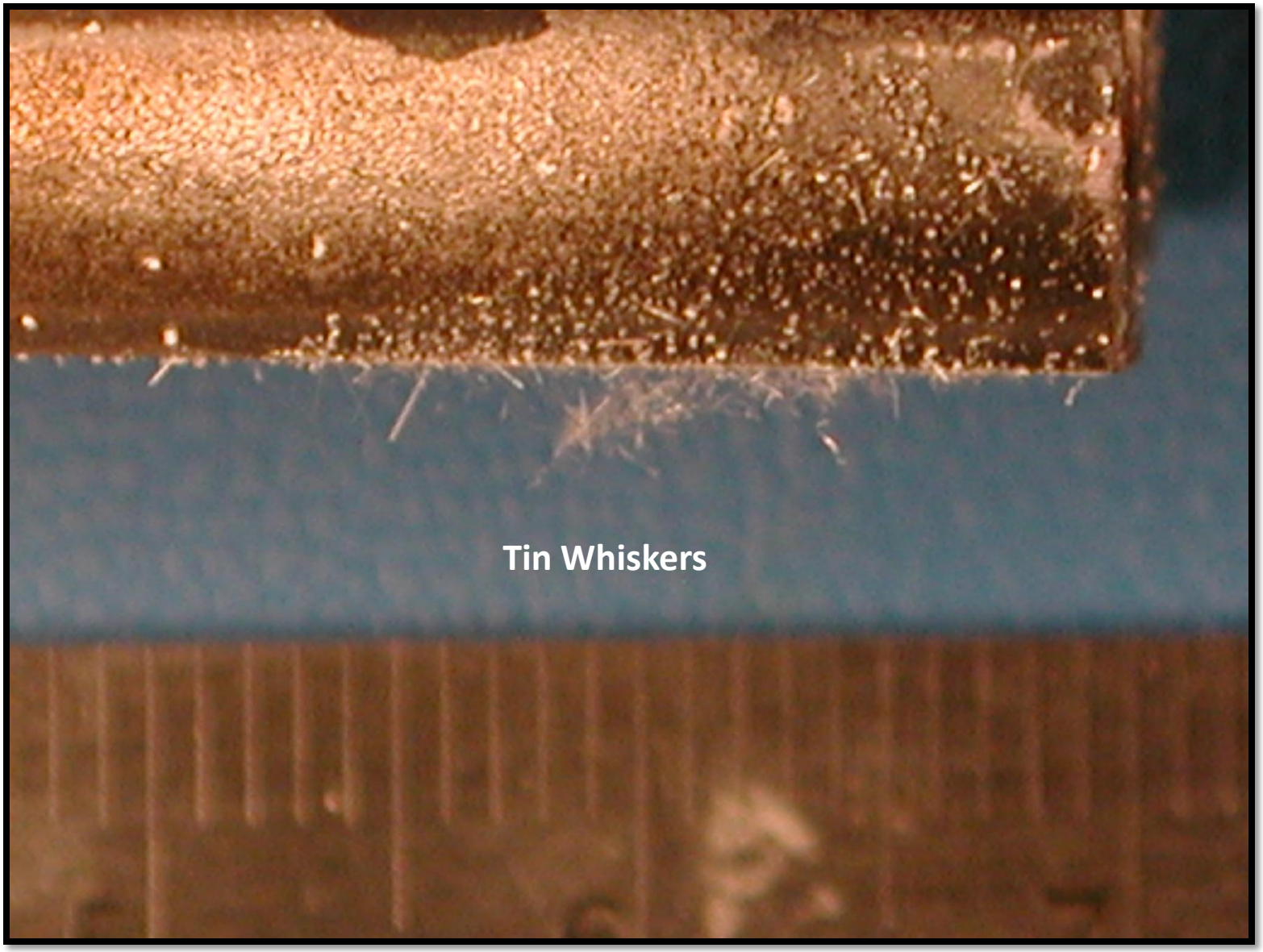
Inspections by Jay Brusse


Helix
MADE IN CHINA
"Cut End"
"UN-Cut End"

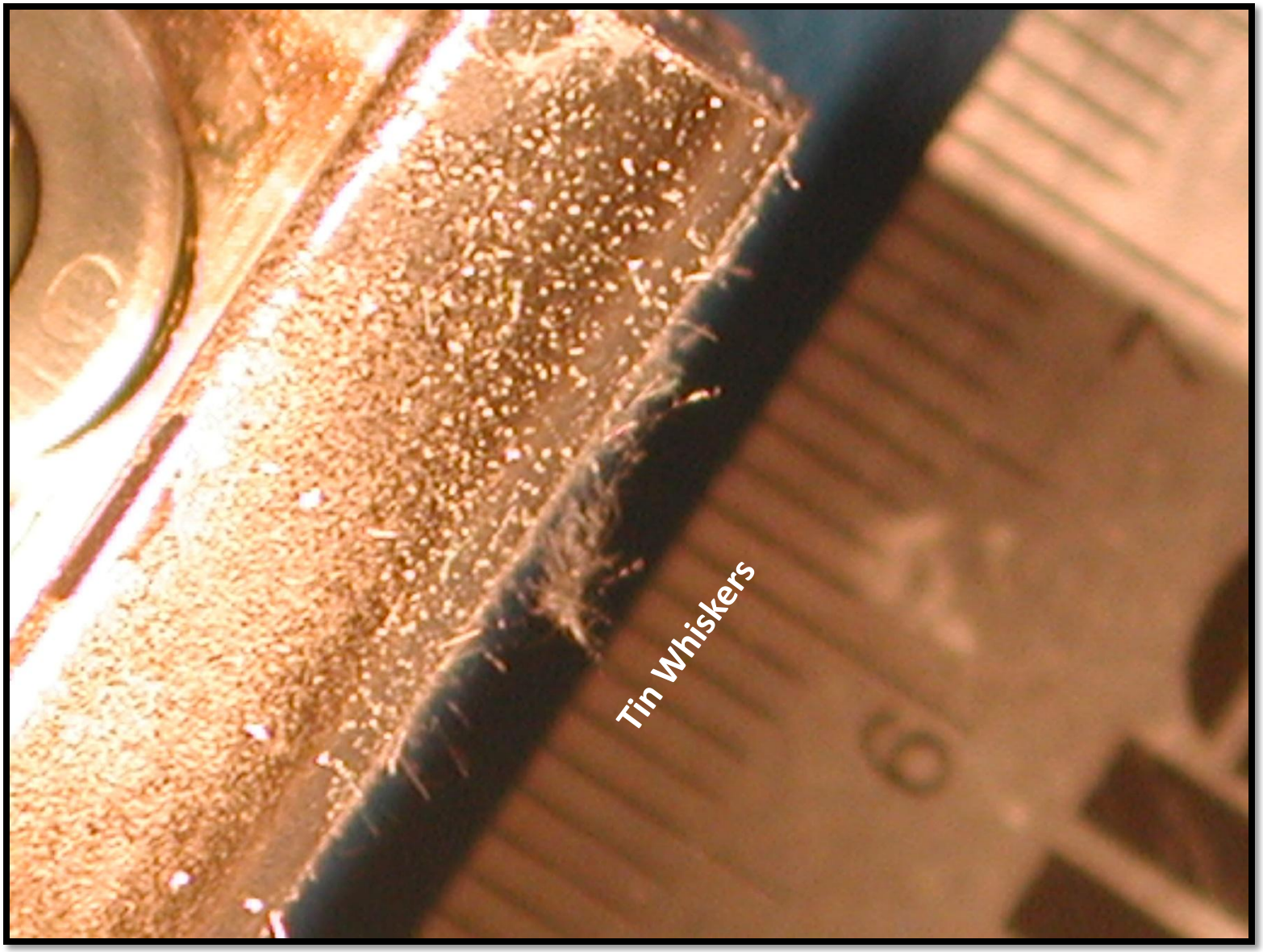

"Shoulder"
"Shoulder"
1
MM
2
3
4

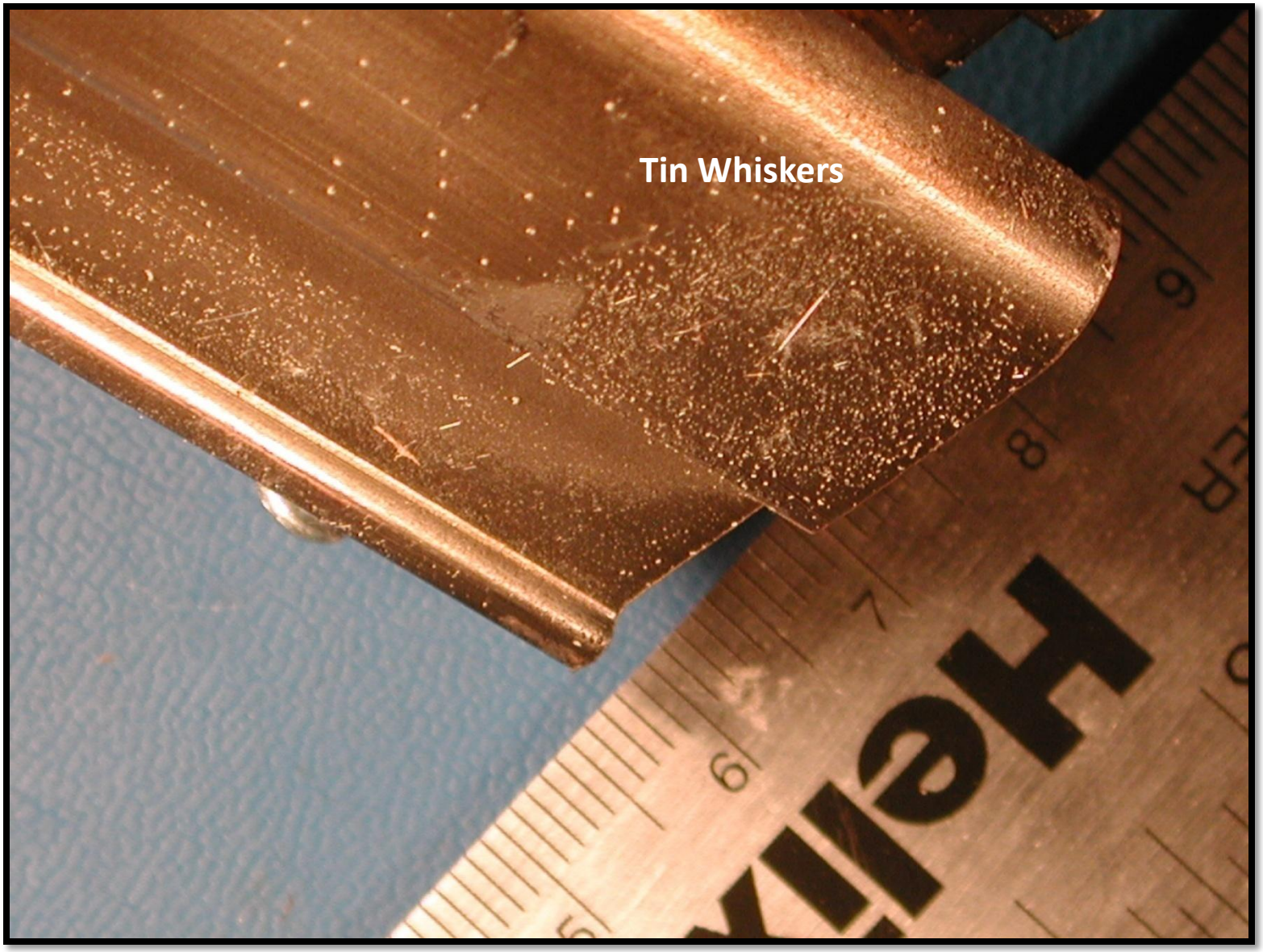


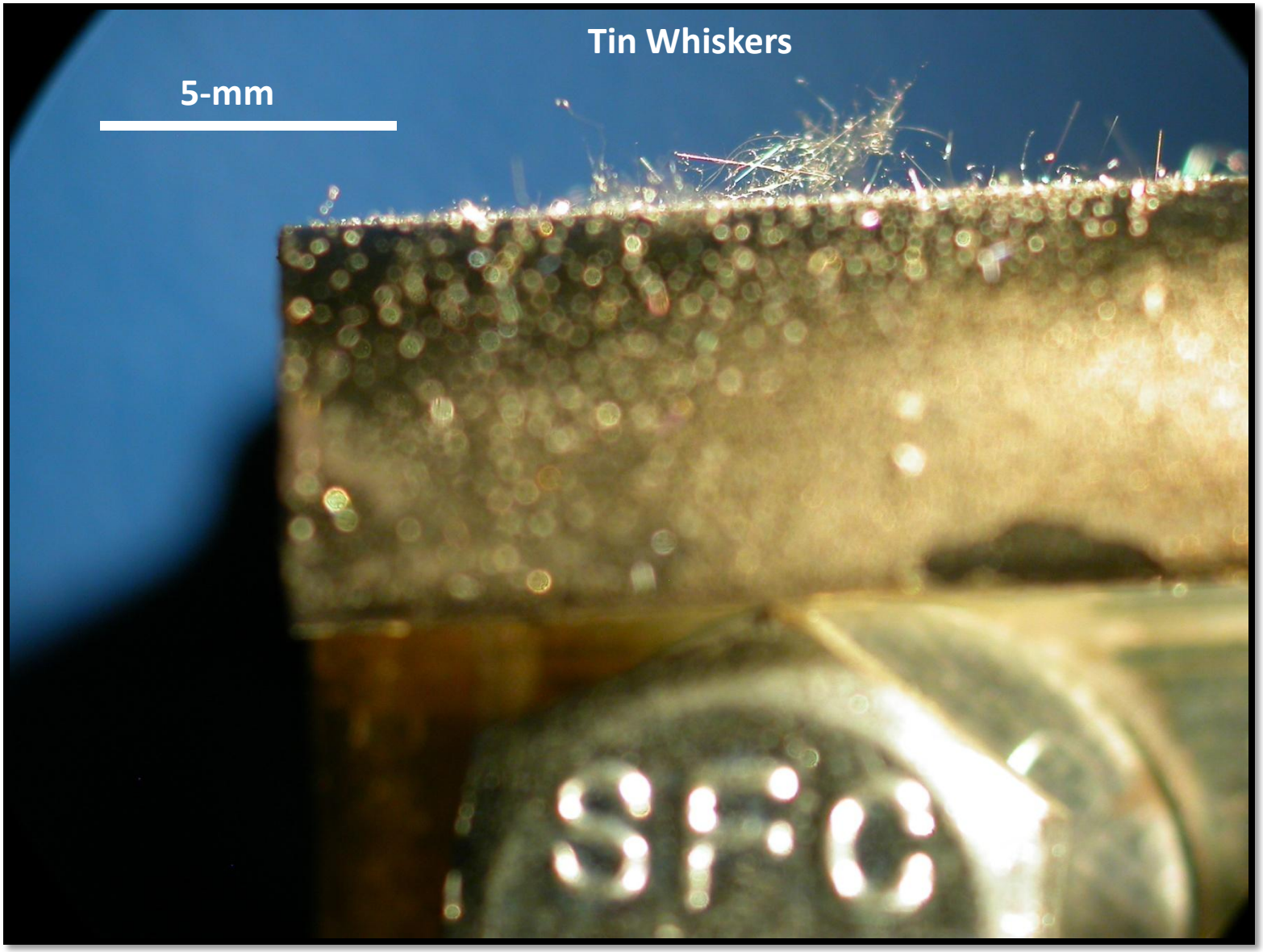
"Blackened" End of Bus Rail with High Density (#/area) of Tin Whiske

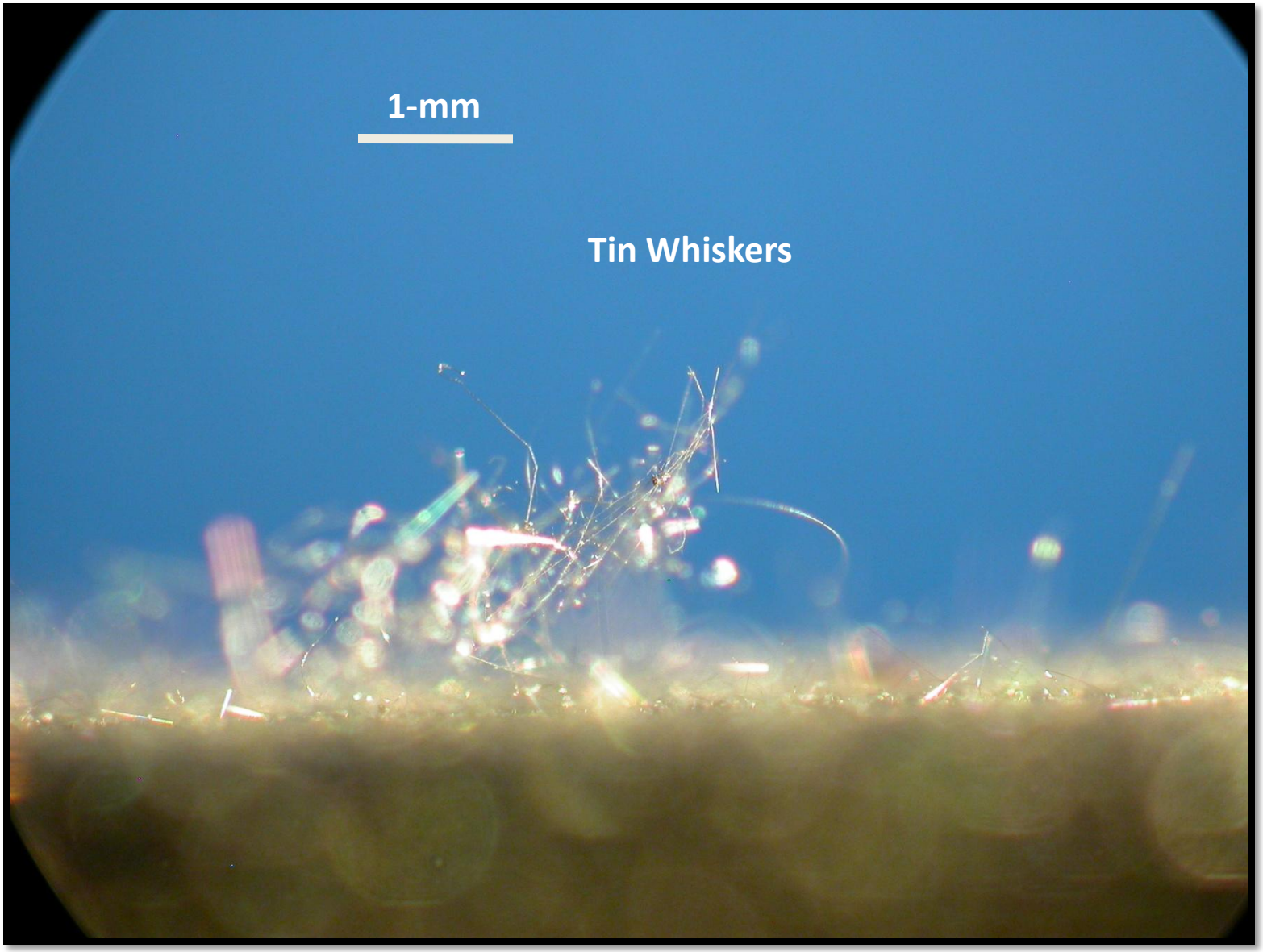

Tin Whiskers

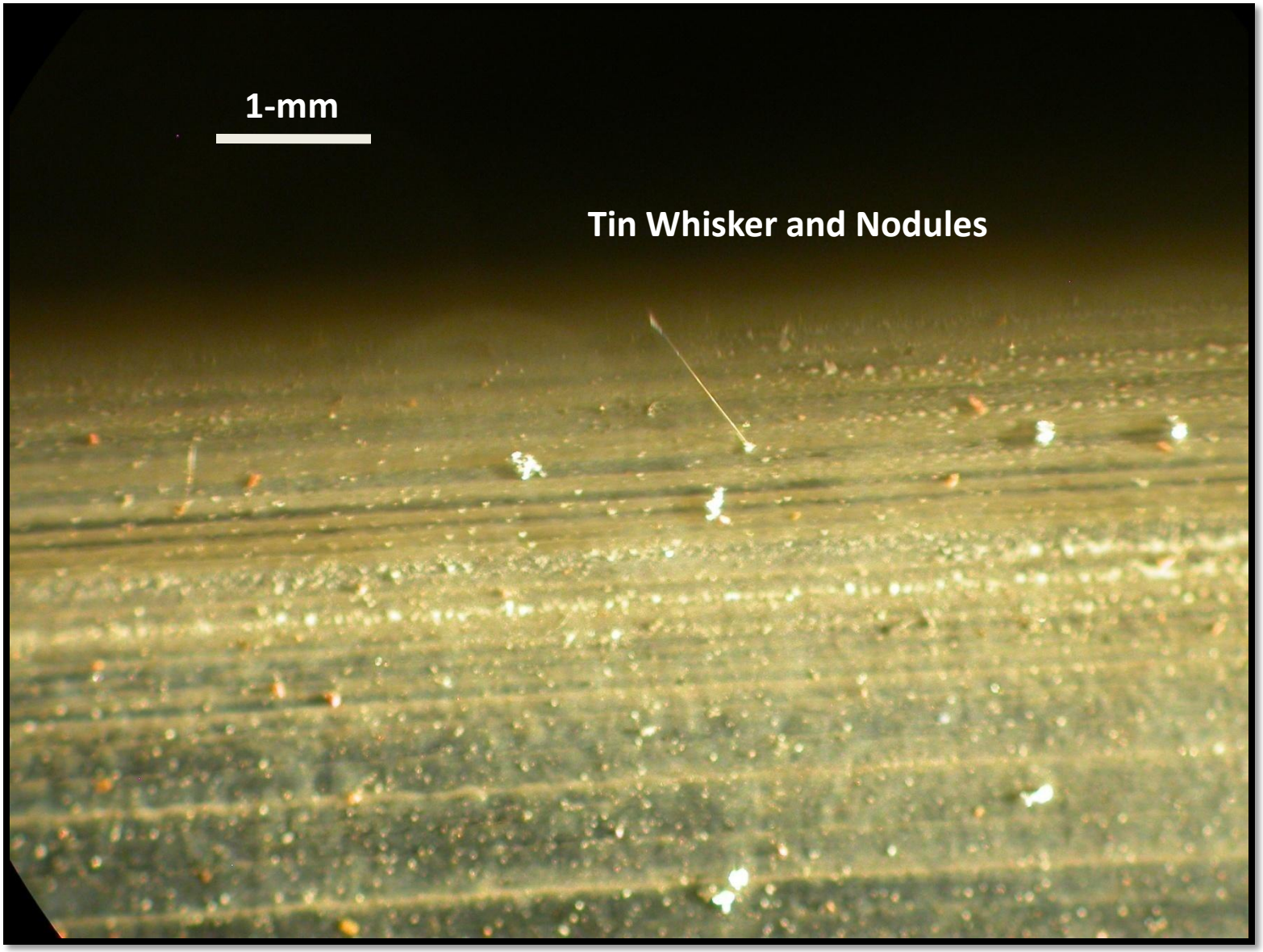

Tin Whiskers
5
6
7


Tin Whiskers


Tin Whiskers


Tin Whiskers
5-mm
SFC

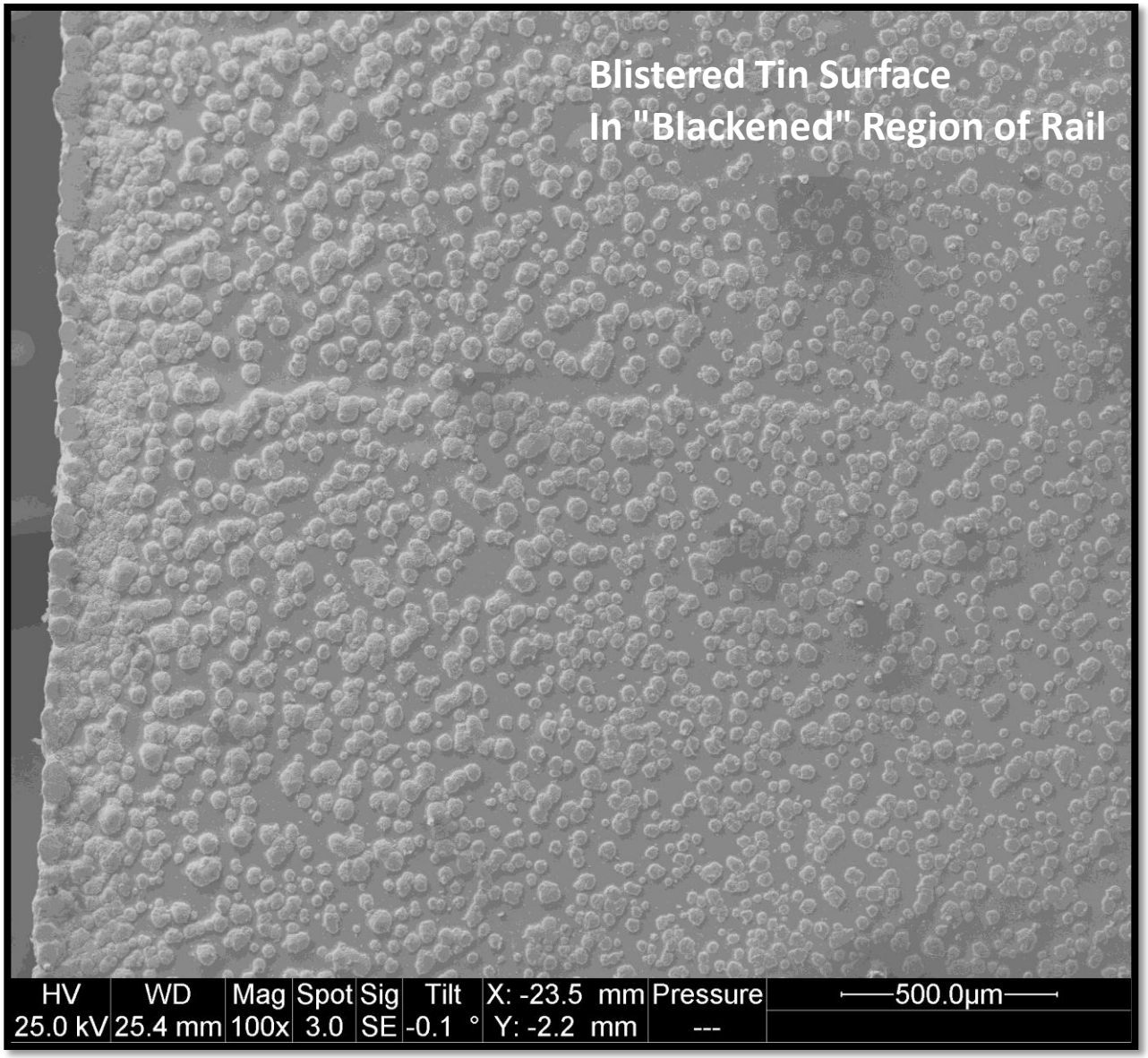

1-mm
Tin Whiskers


1-mm
Tin Whisker and Nodules

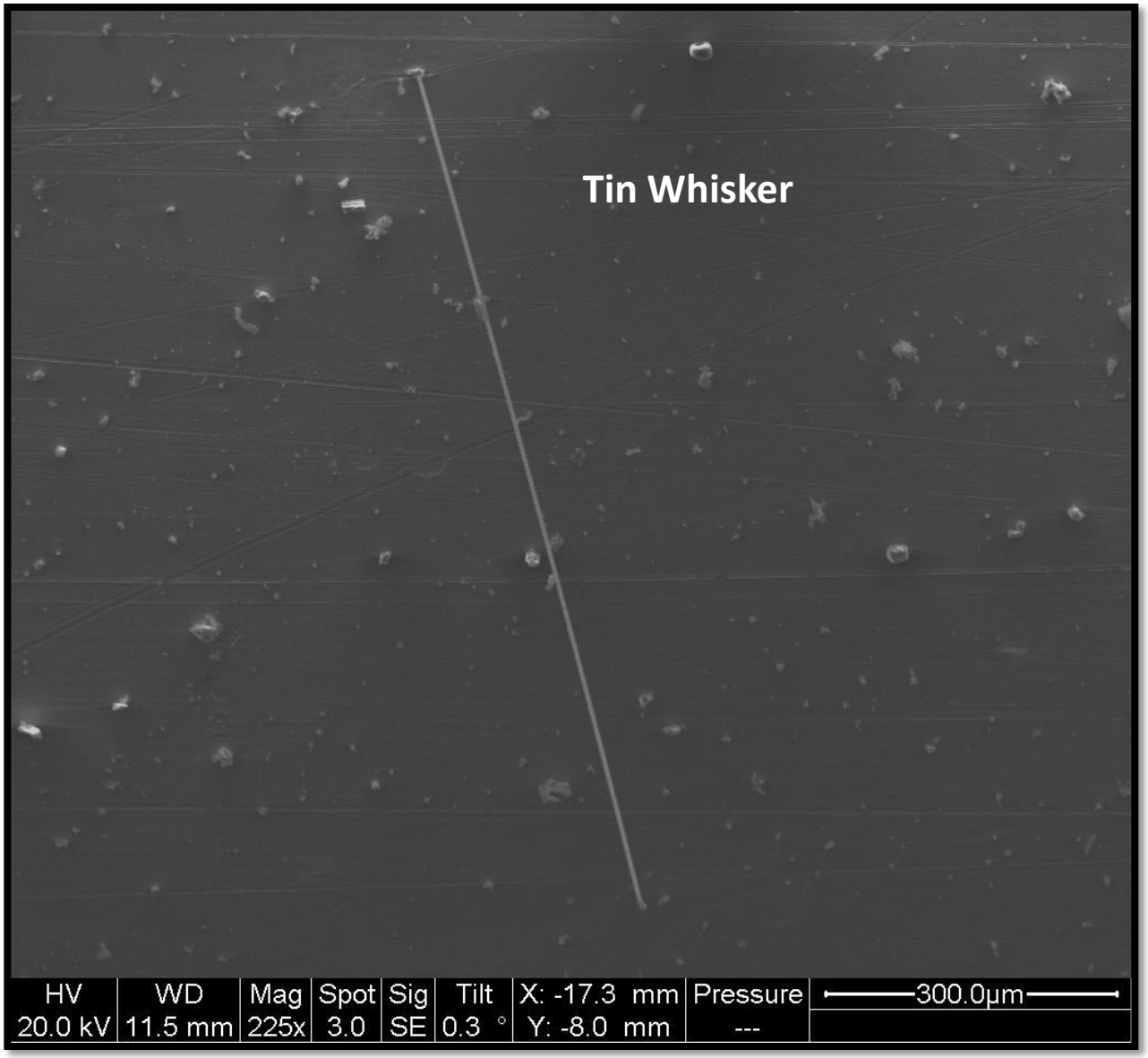
# Scanning Electron Microscopy/ Energy Dispersive X-ray Spectroscopy (SEM/EDS)

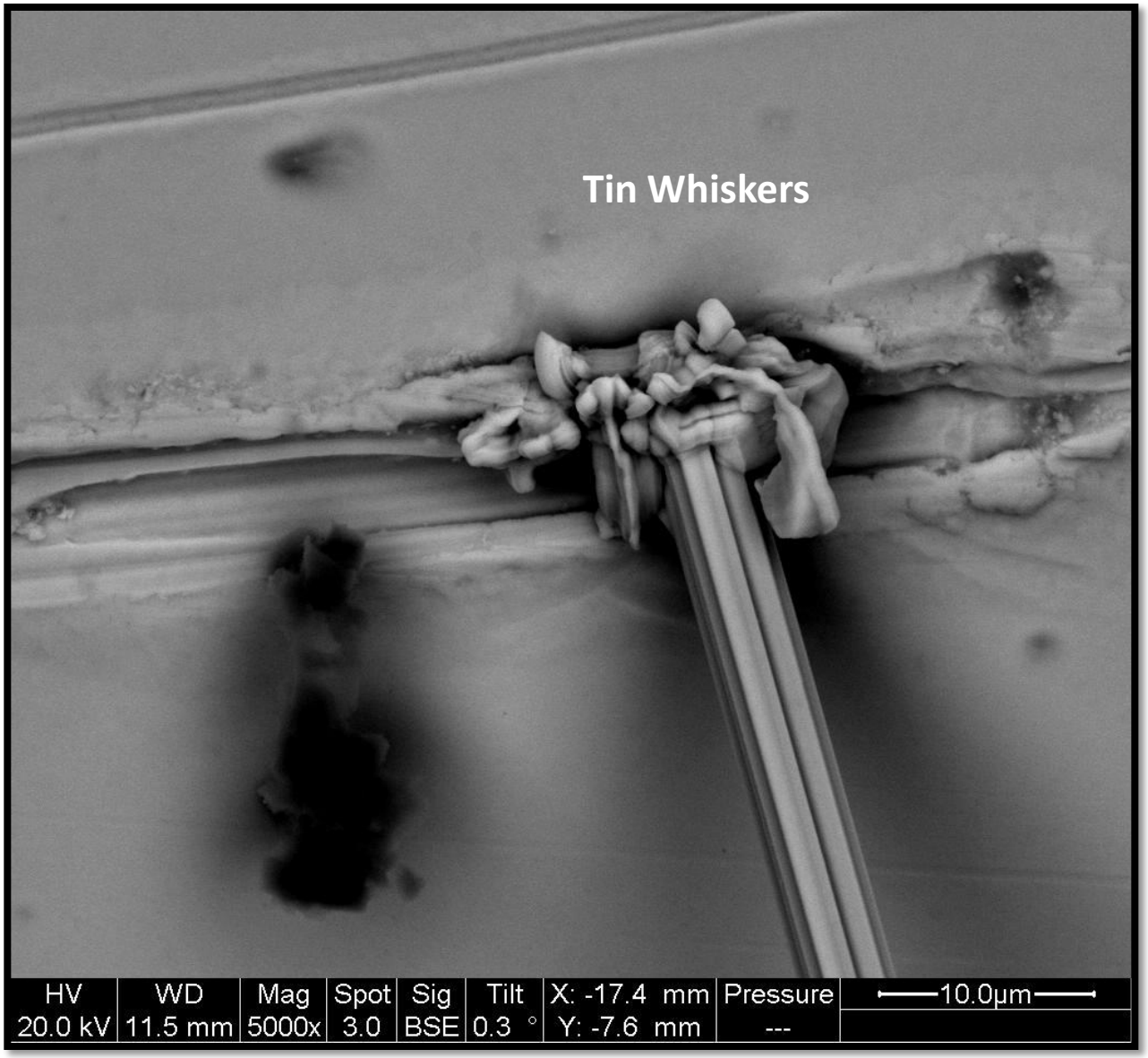
EDS is a non-destructive method for measuring the elemental composition of a surface.

Analysis by Lyudmyla Panashchenko


Blistered Tin Surface
In "Blackened" Region of Rail
HV
25.0 kV
WD
25.4 mm
Mag
100x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -23.5 mm
Y: -2.2 mm
Pressure
---
500.0µm

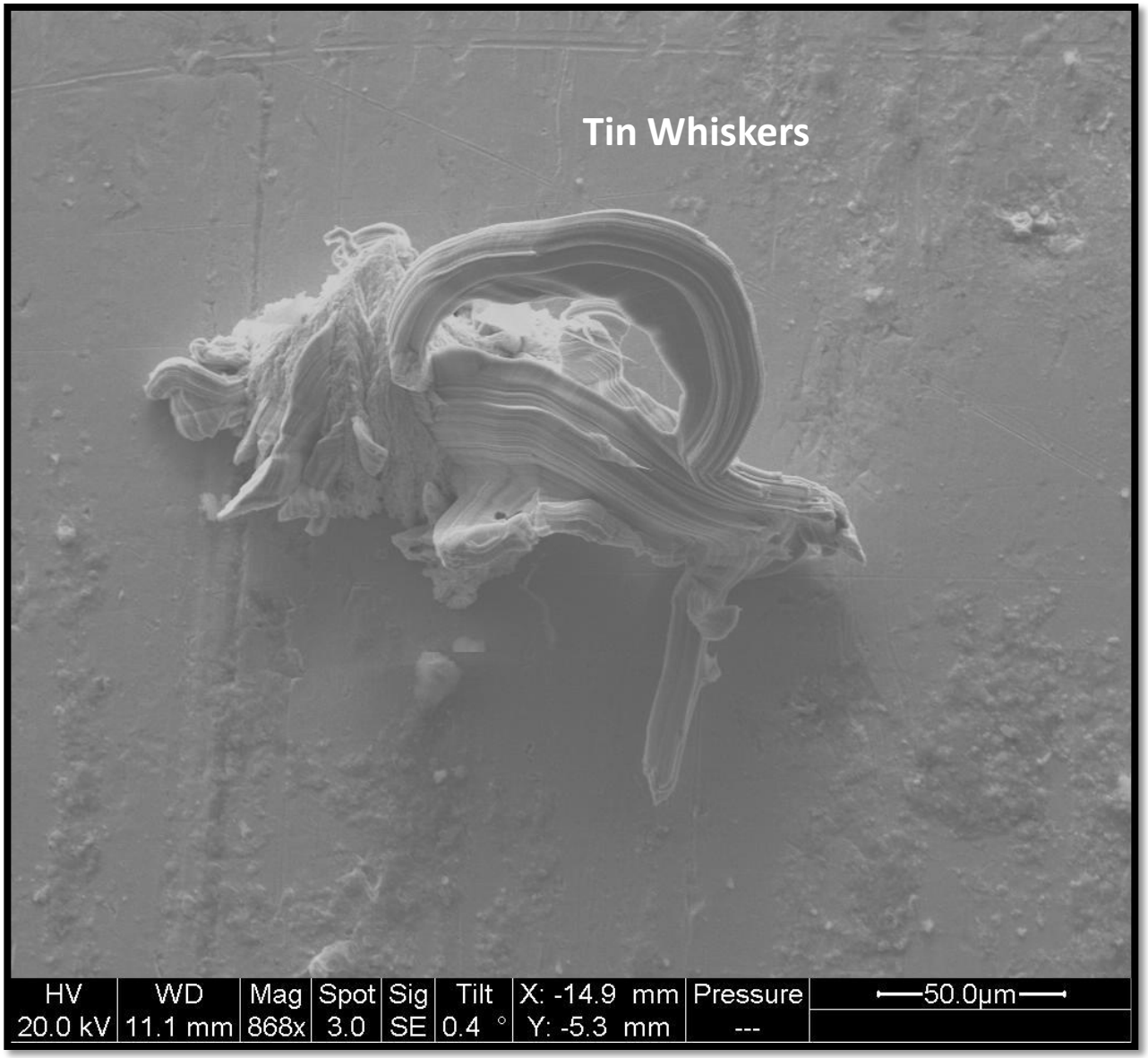

Tin Whisker
HV
20.0 kV
WD
11.5 mm
Mag
100x
Spot
3.0
Sig
SE
Tilt
0.4 °
X: -17.3 mm
Y: -8.0 mm
Pressure
---
500.0µm


Tin Whisker
HV
20.0 kV
WD
11.5 mm
Mag
225x
Spot
3.0
Sig
SE
Tilt
0.3 °
X: -17.3 mm
Y: -8.0 mm
Pressure
---
300.0µm


Tin Whiskers
HV
20.0 kV
WD
11.5 mm
Mag
5000x
Spot
3.0
Sig
BSE
Tilt
0.3 °
X: -17.4 mm
Y: -7.6 mm
Pressure
---
10.0µm

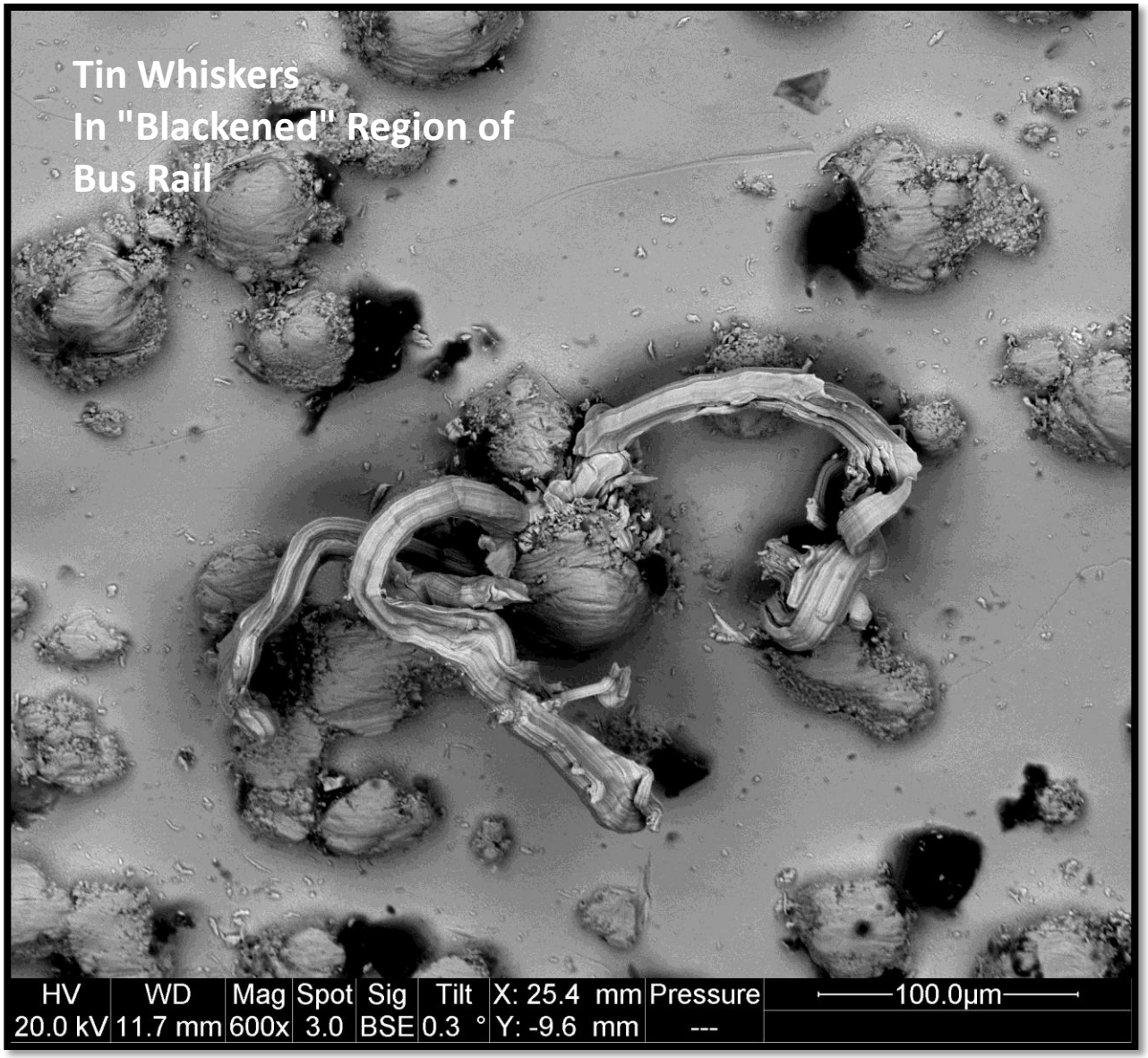

Tin Whiskers
69.78 µm
HV
20.0 kV
Spot
3.0
Mag
673x
Det
Etd
Sig
SE
WD
12.16 mm
Pressure
---
50 µm

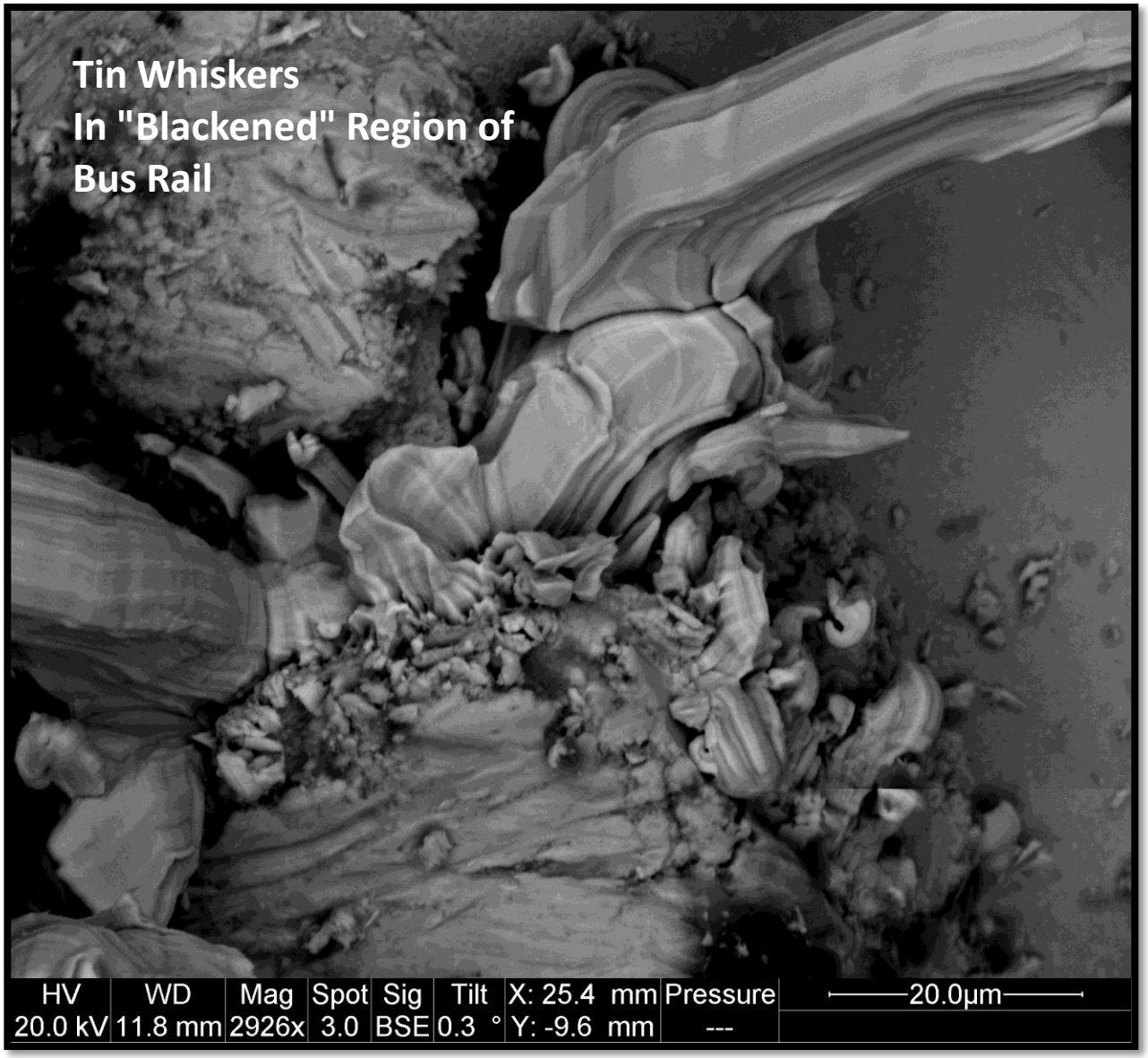

Tin Whiskers
HV
20.0 kV
Spot
3.0
Mag
600x
Det
SSD
Sig
BSE
WD
11.22 mm
Pressure
---
100 µm

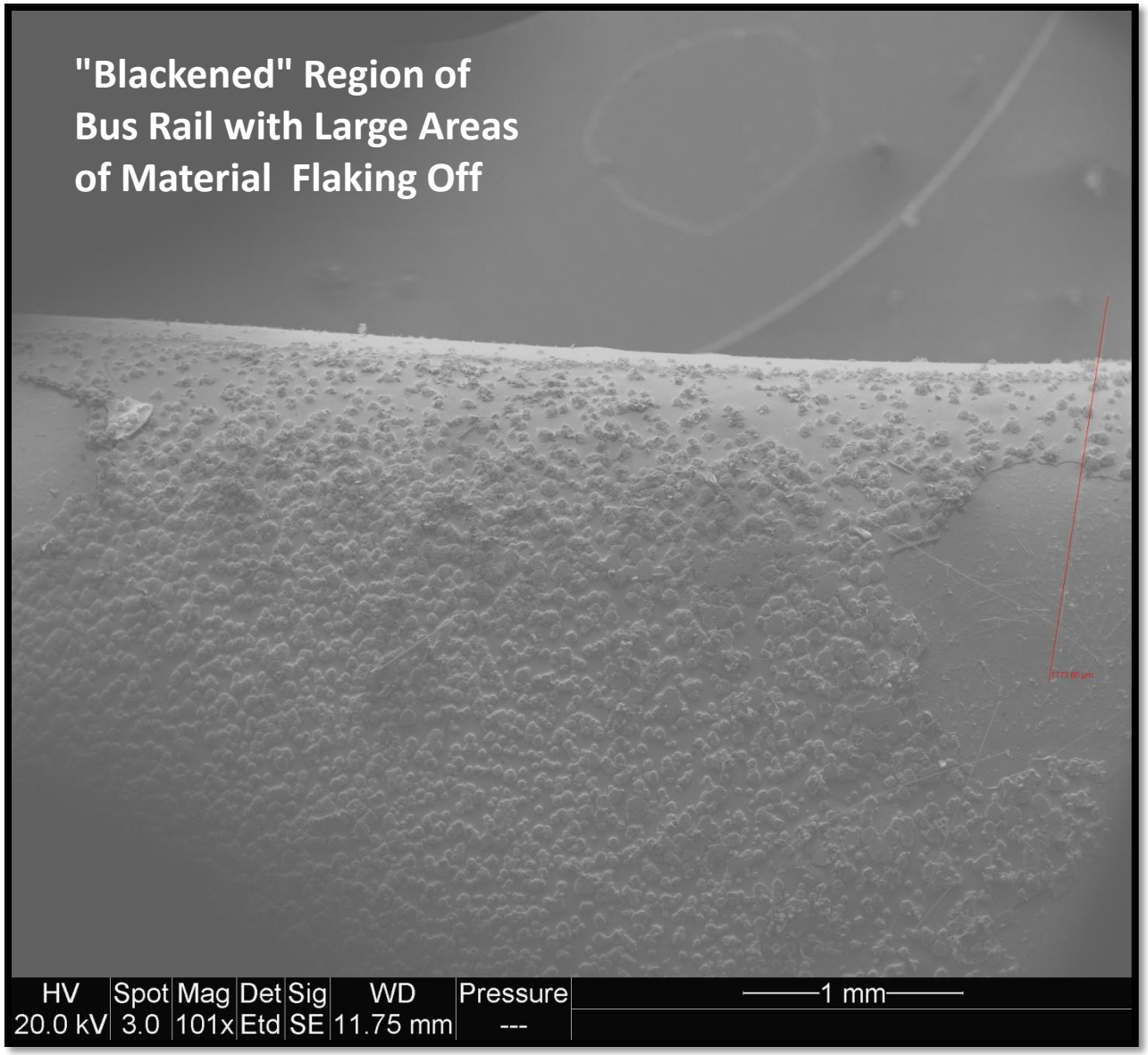

Tin Whiskers
HV
20.0 kV
WD
11.1 mm
Mag
868x
Spot
3.0
Sig
SE
Tilt
0.4 °
X: -14.9 mm
Y: -5.3 mm
Pressure
---
50.0µm


Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
20.0 kV
WD
12.2 mm
Mag
80x
Spot
3.0
Sig
BSE
Tilt
0.3 °
X: 25.5 mm
Y: -10.1 mm
Pressure
---
500.0µm

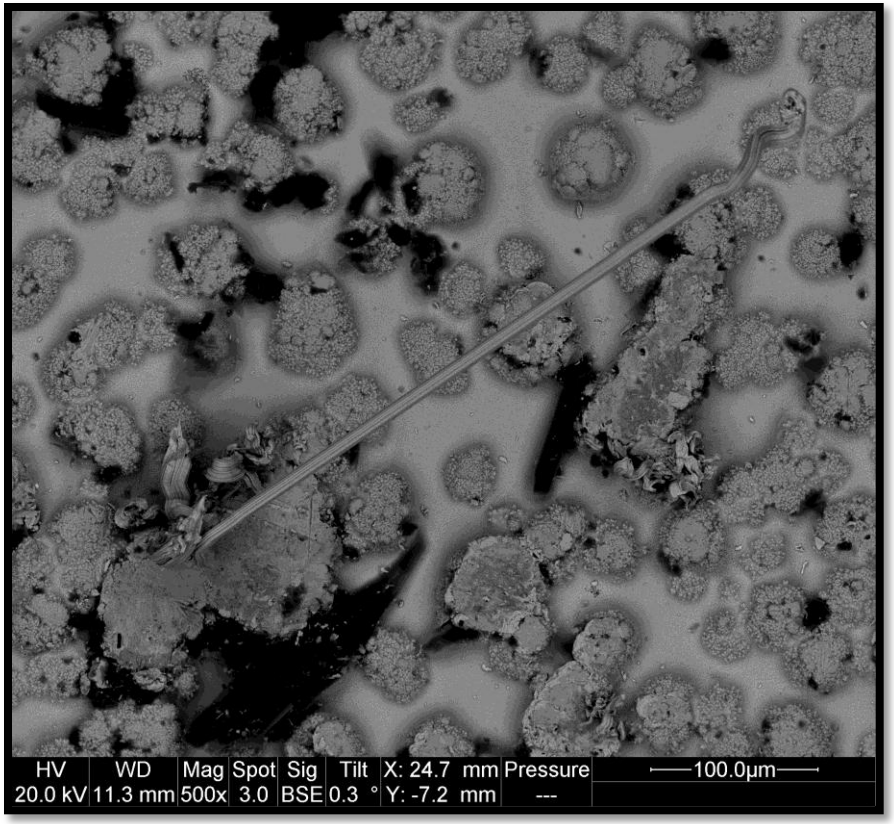

Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
20.0 kV
WD
12.7 mm
Mag
420x
Spot
3.0
Sig
BSE
Tilt
0.4 °
X: 24.4 mm
Y: -11.0 mm
Pressure
---
100.0µm


Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
20.0 kV
WD
11.7 mm
Mag
600x
Spot
3.0
Sig
BSE
Tilt
0.3 °
X: 25.4 mm
Y: -9.6 mm
Pressure
---
100.0µm

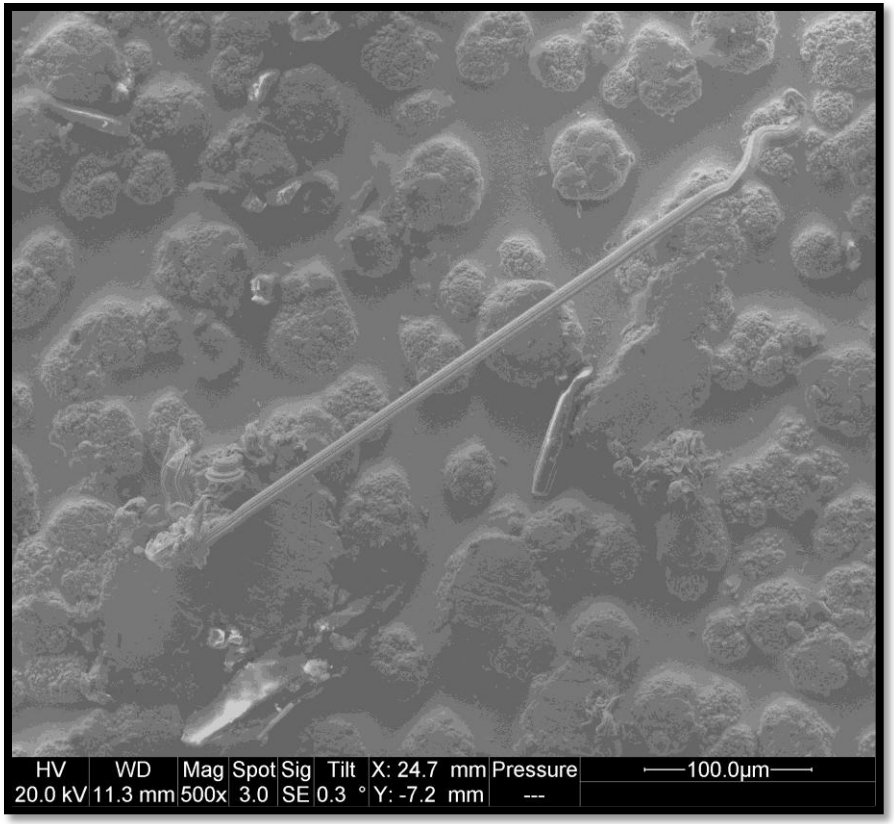

Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
20.0 kV
WD
11.8 mm
Mag
2926x
Spot
3.0
Sig
BSE
Tilt
0.3 °
X: 25.4 mm
Y: -9.6 mm
Pressure
---
20.0µm


"Blackened" Region of
Bus Rail with Large Areas
of Material Flaking Off
HV
20.0 kV
Spot
3.0
Mag
101x
Det
Etd
Sig
SE
WD
11.75 mm
Pressure
---
1 mm

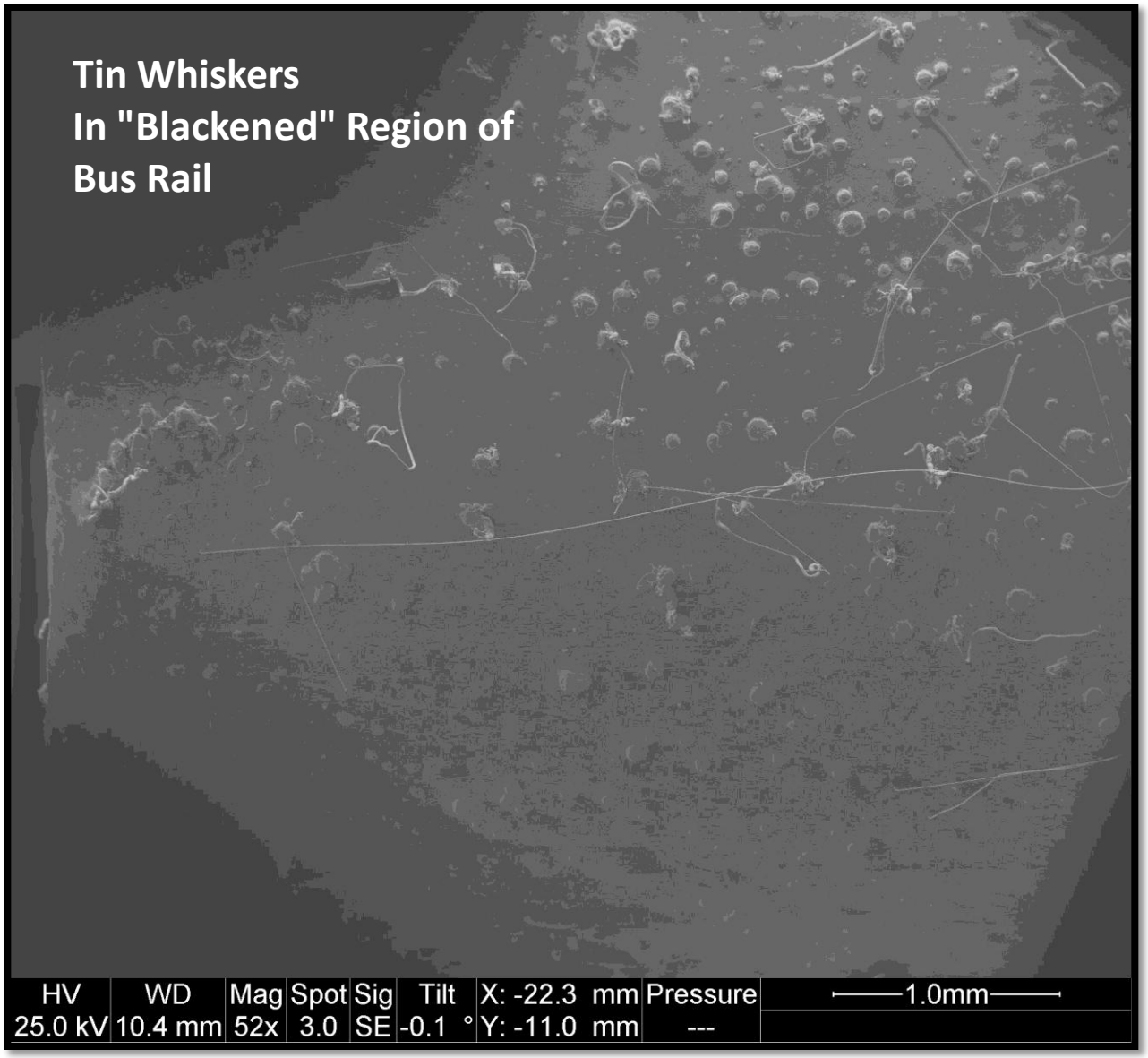
## Tin Whiskers In "Blackened" Region of Bus Rail

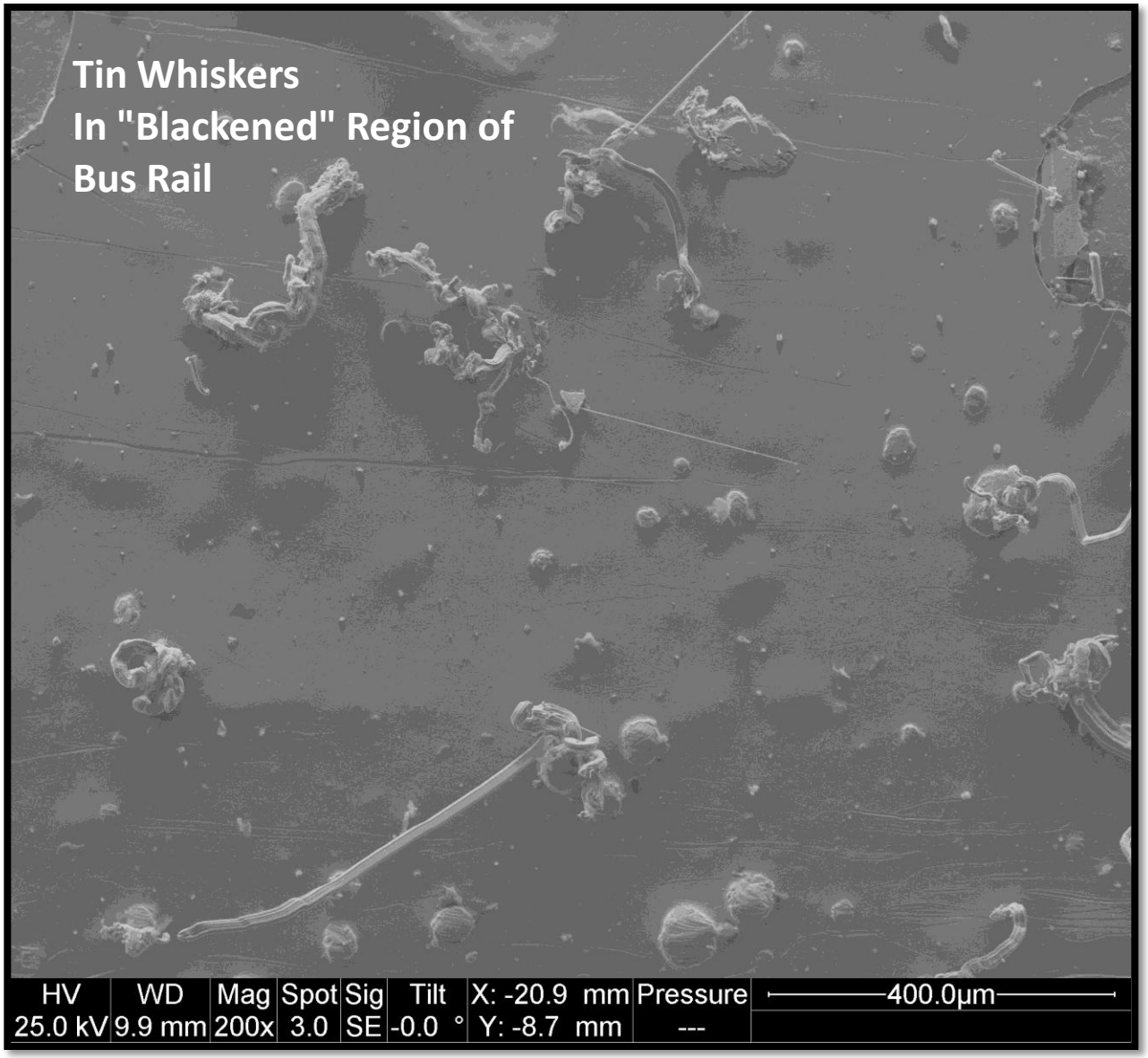



Back Scatter Electron (BSE) view – difference in contrast represents different materials. Lighter colors are elements higher on periodic chart (in this case – tin), darker colors are elements lower on the periodic chart (in this case small debris, probably carbon)

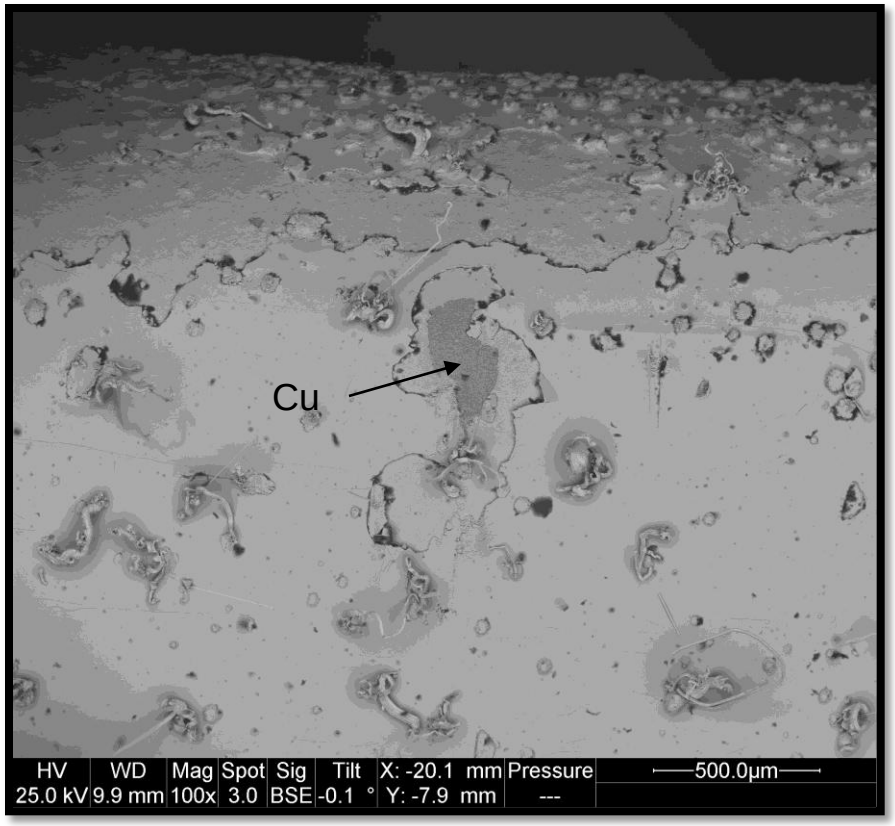



Secondary Electron (SE) view – topographical image

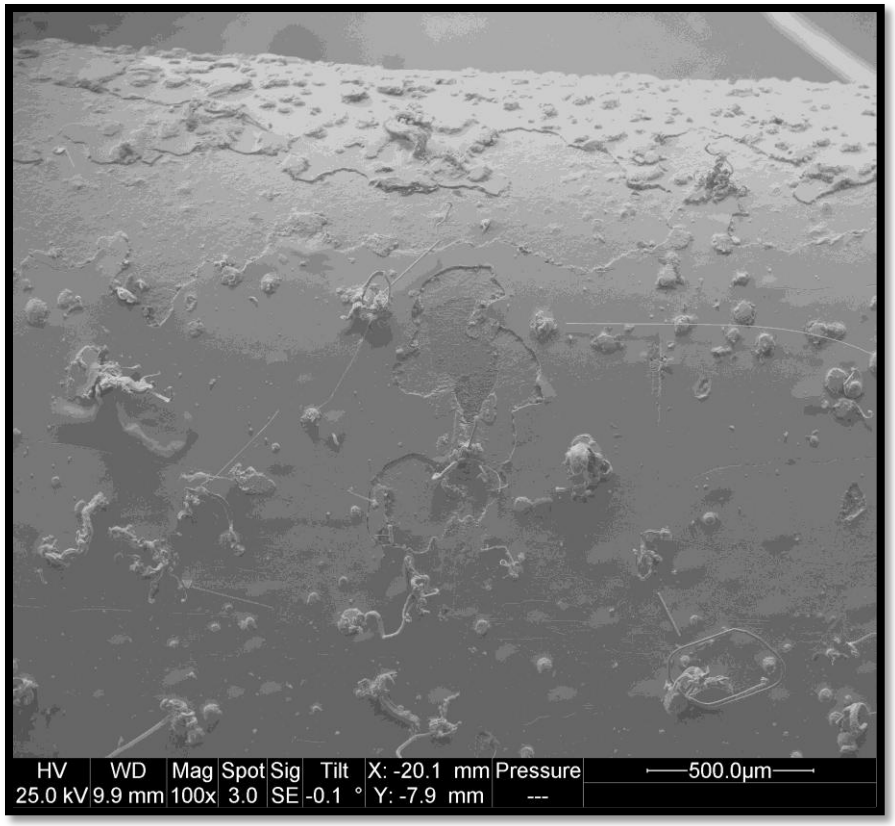

Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
25.0 kV
WD
10.4 mm
Mag
52x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -22.3 mm
Y: -11.0 mm
Pressure
---
1.0mm


Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
25.0 kV
WD
9.9 mm
Mag
200x
Spot
3.0
Sig
SE
Tilt
-0.0 °
X: -20.9 mm
Y: -8.7 mm
Pressure
---
400.0µm

# Tin Whiskers In "Blackened" Region of Bus Rail



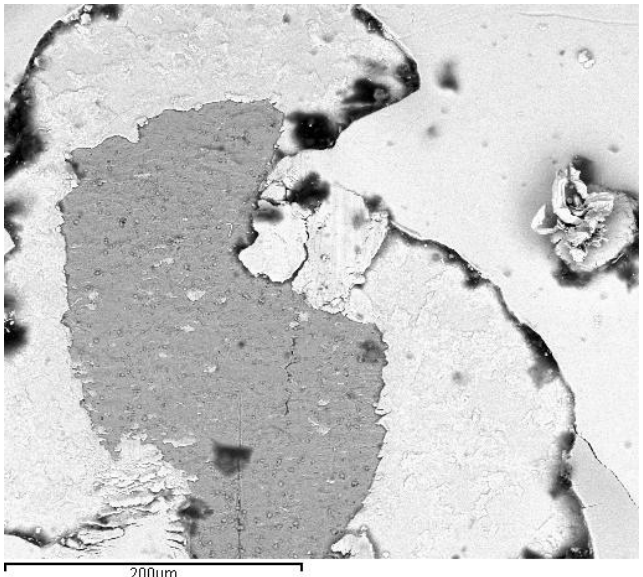

BSE view – difference in materials

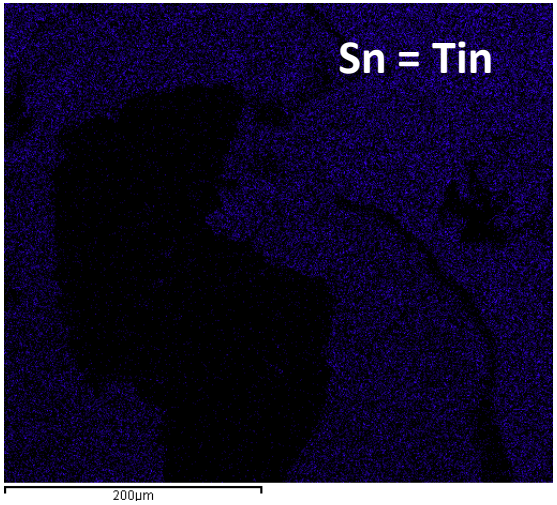


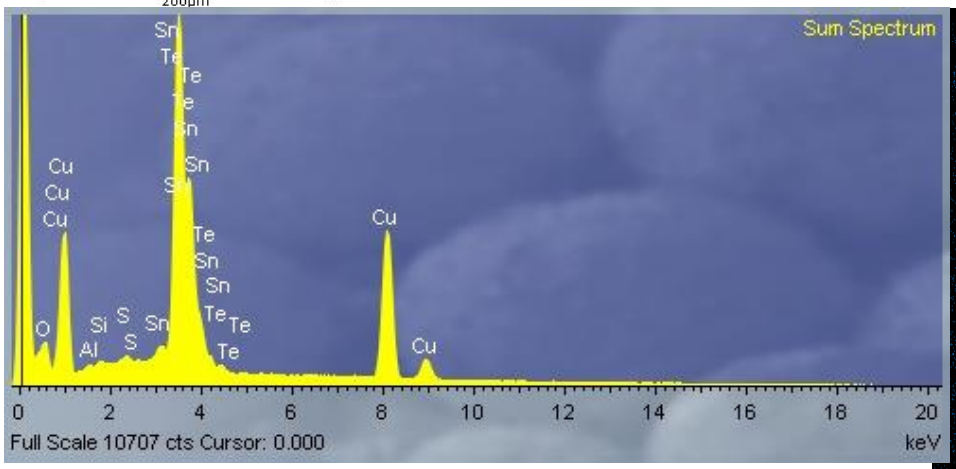

SE view – topographical image

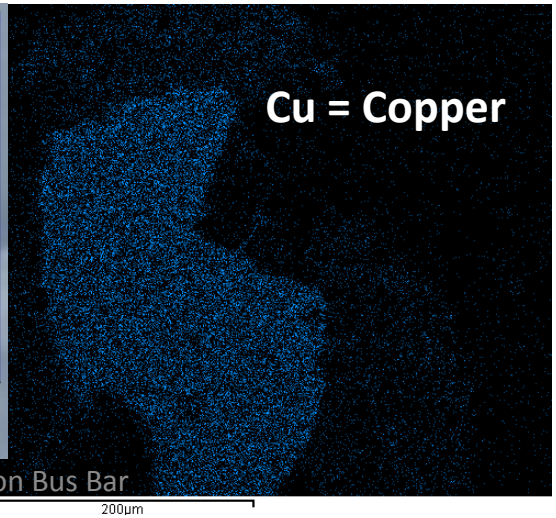
Note: there seems to be flaking off of some tin coating. BSE image shows that most of flaked-off region exposes more tin underneath, but there is one area that exposes copper (Cu). See next slide for EDS analysis of this region

# EDS Analysis of an Area Where Tin Coating Has Flaked Off

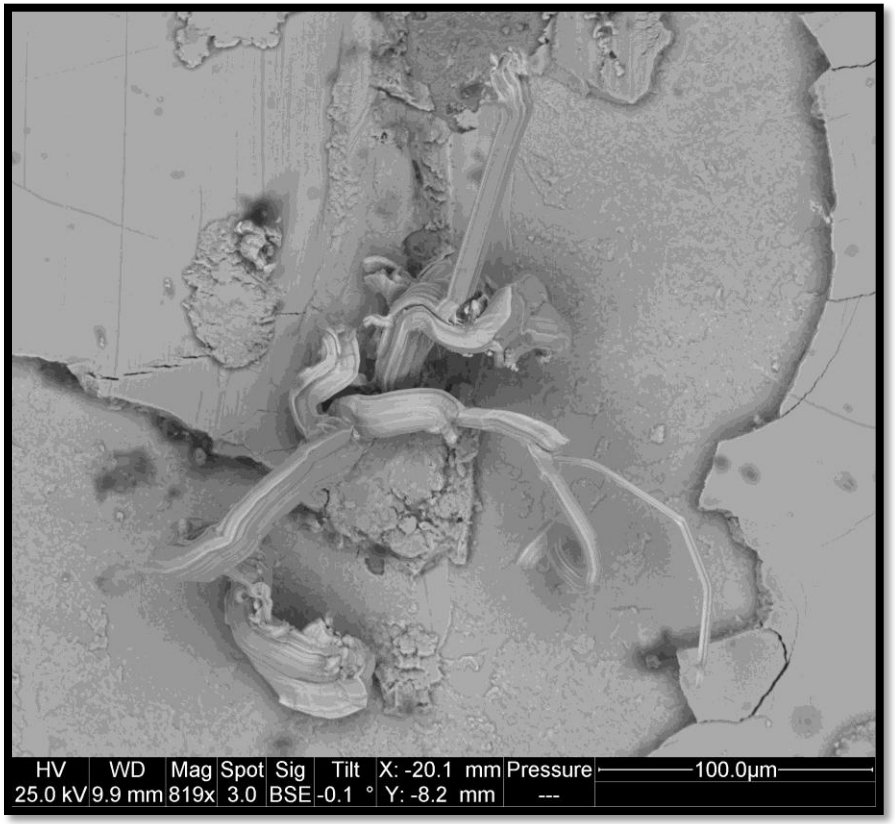


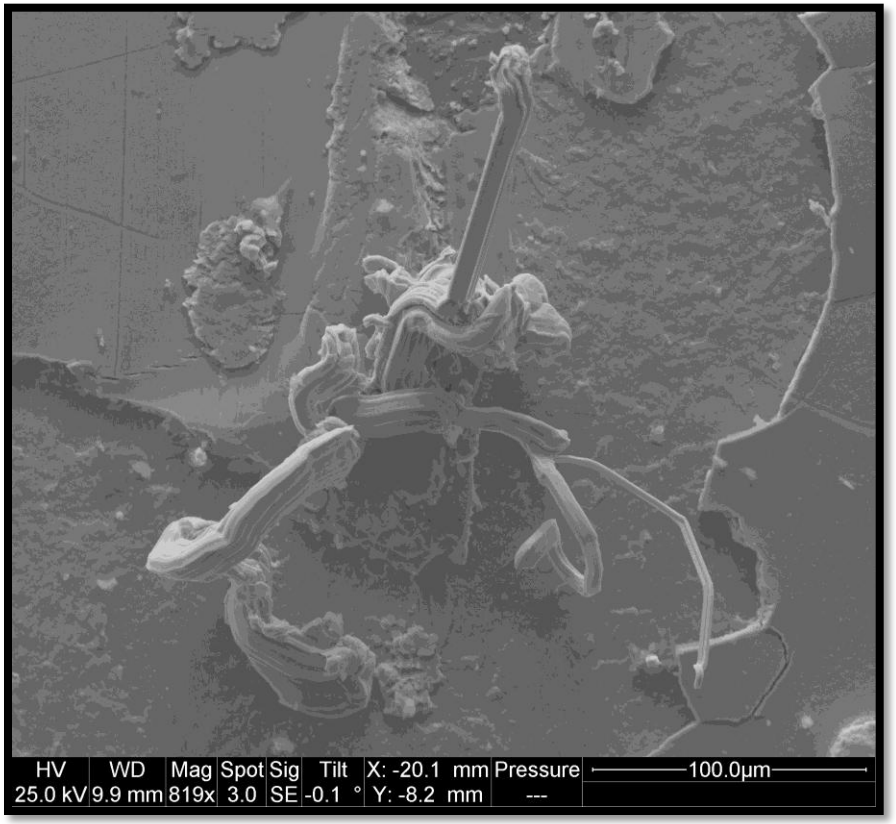



# Tin Whiskers In "Blackened" Region of Bus Rail

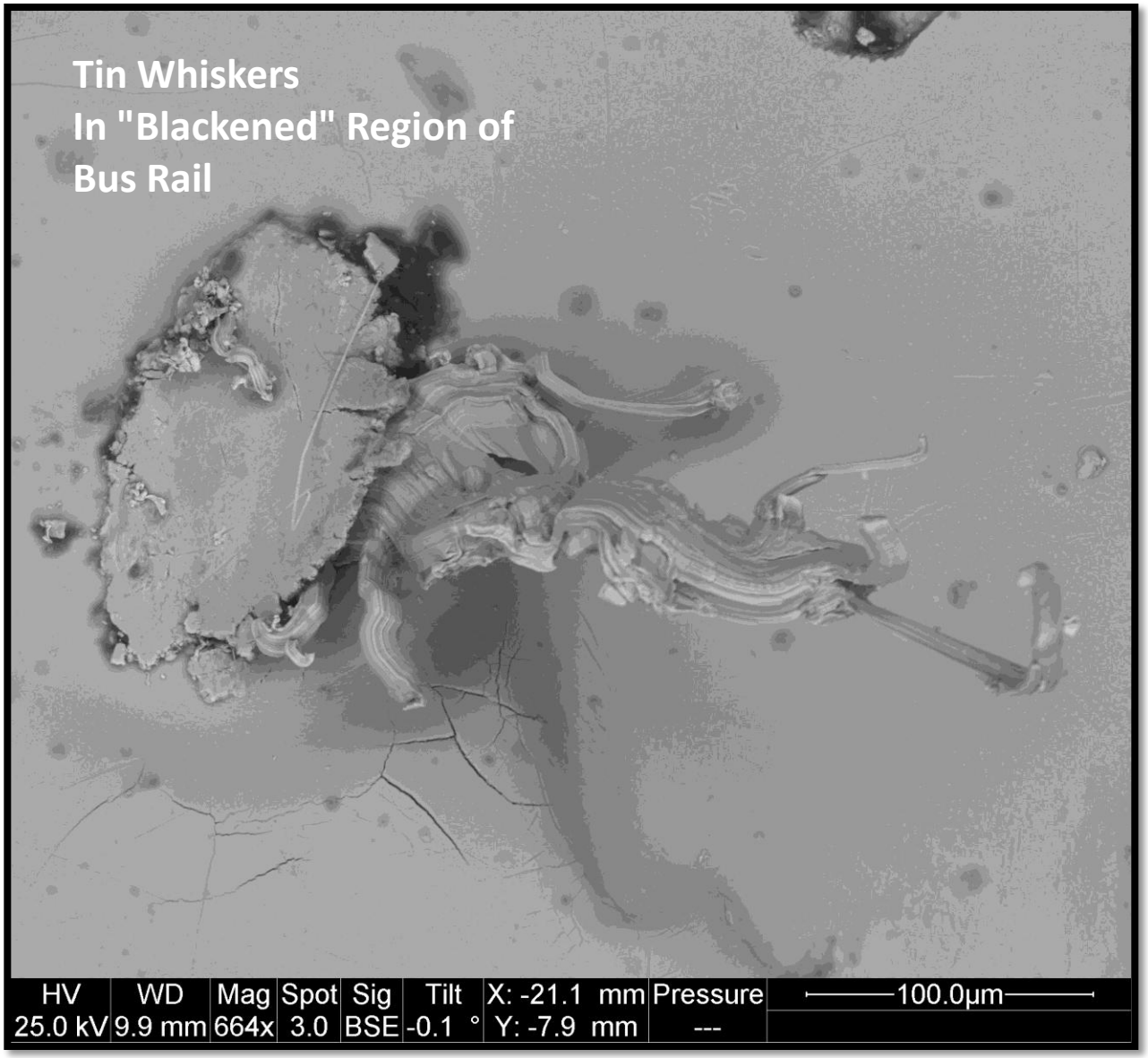


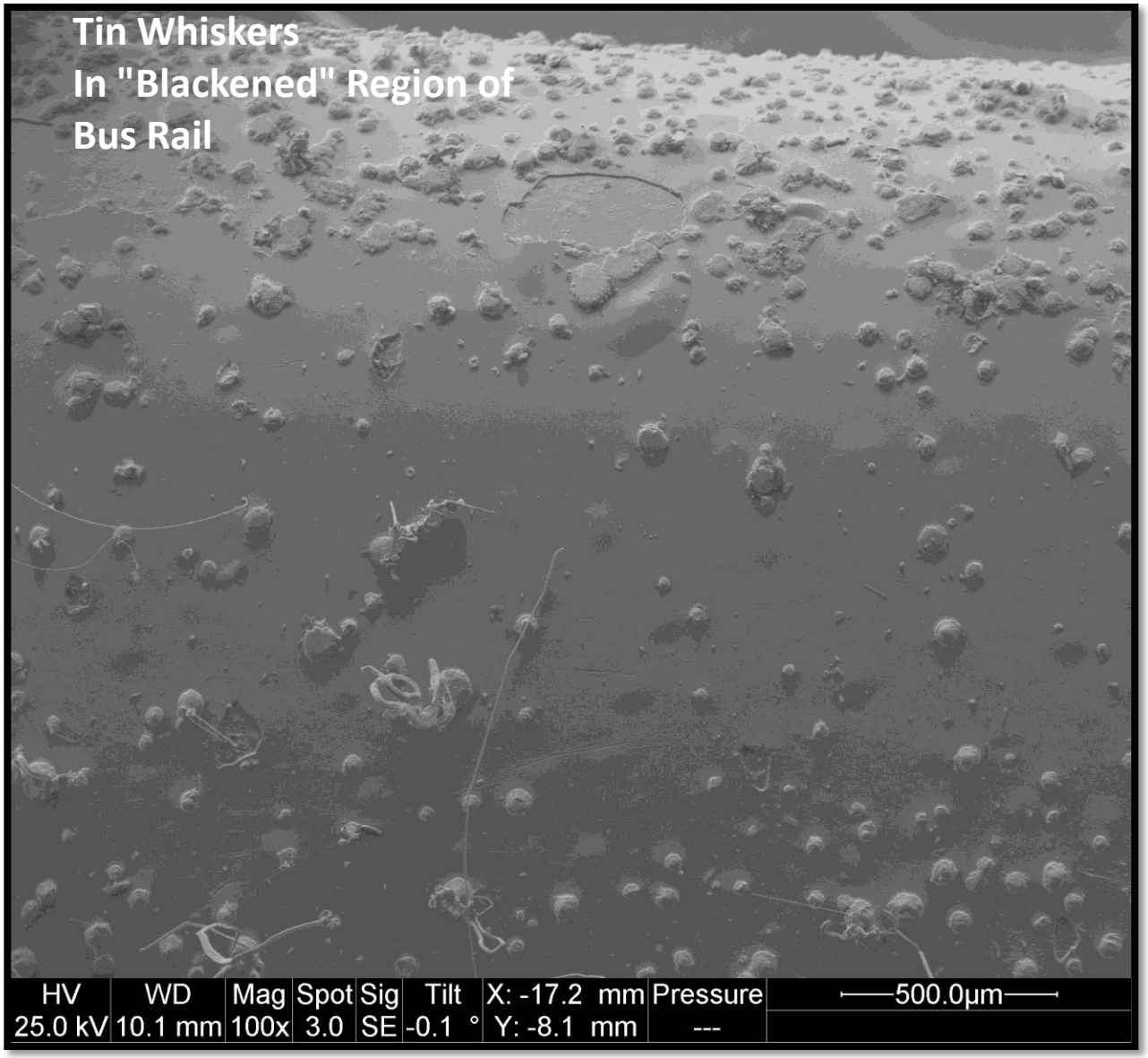

BSE view – difference in materials



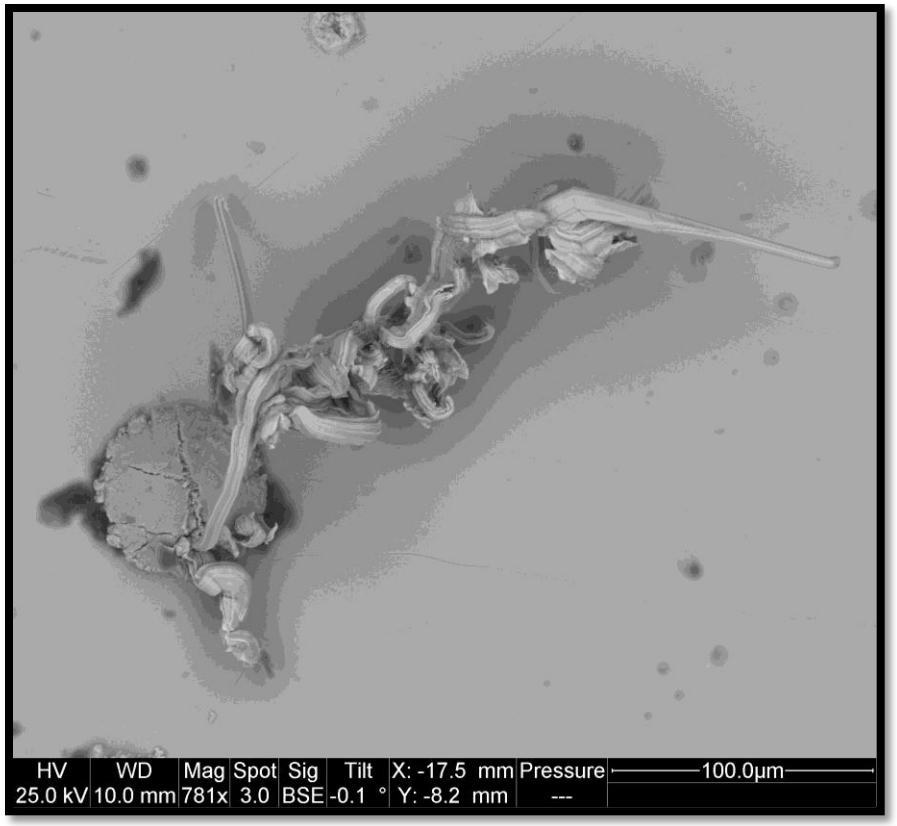

SE view – topographical image

The smoother regions in the picture are from a top layer of tin, while rougher regions are an exposed layer of tin from top layer flaking off

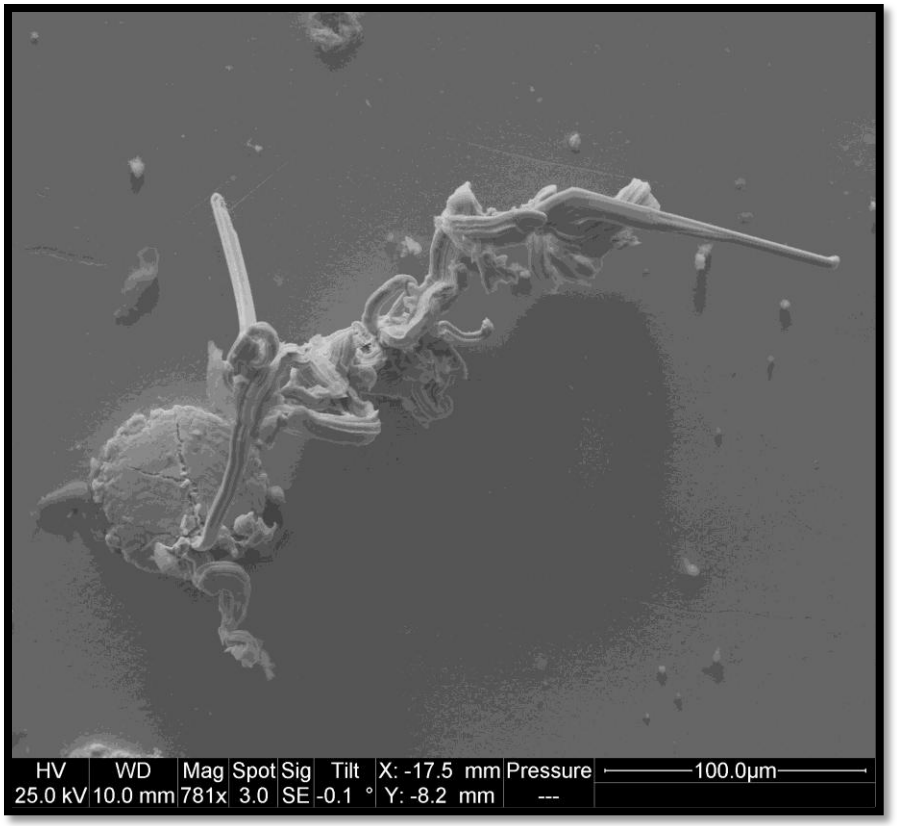

Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
25.0 kV
WD
9.9 mm
Mag
664x
Spot
3.0
Sig
BSE
Tilt
-0.1 °
X: -21.1 mm
Y: -7.9 mm
Pressure
---
100.0µm


Tin Whiskers
In "Blackened" Region of
Bus Rail
HV
25.0 kV
WD
10.1 mm
Mag
100x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -17.2 mm
Y: -8.1 mm
Pressure
---
500.0µm

# Tin Whiskers



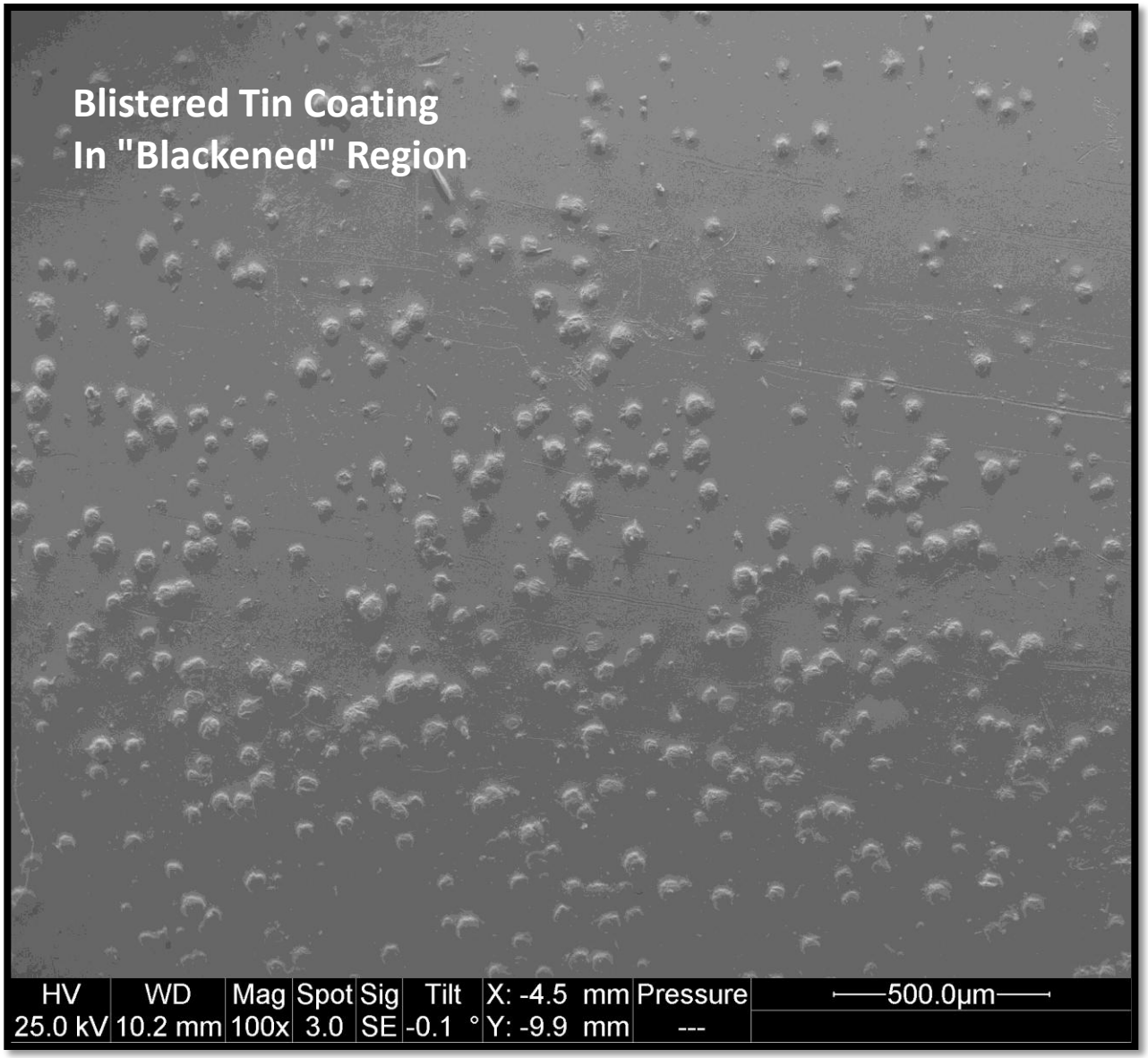

BSE view – difference in materials



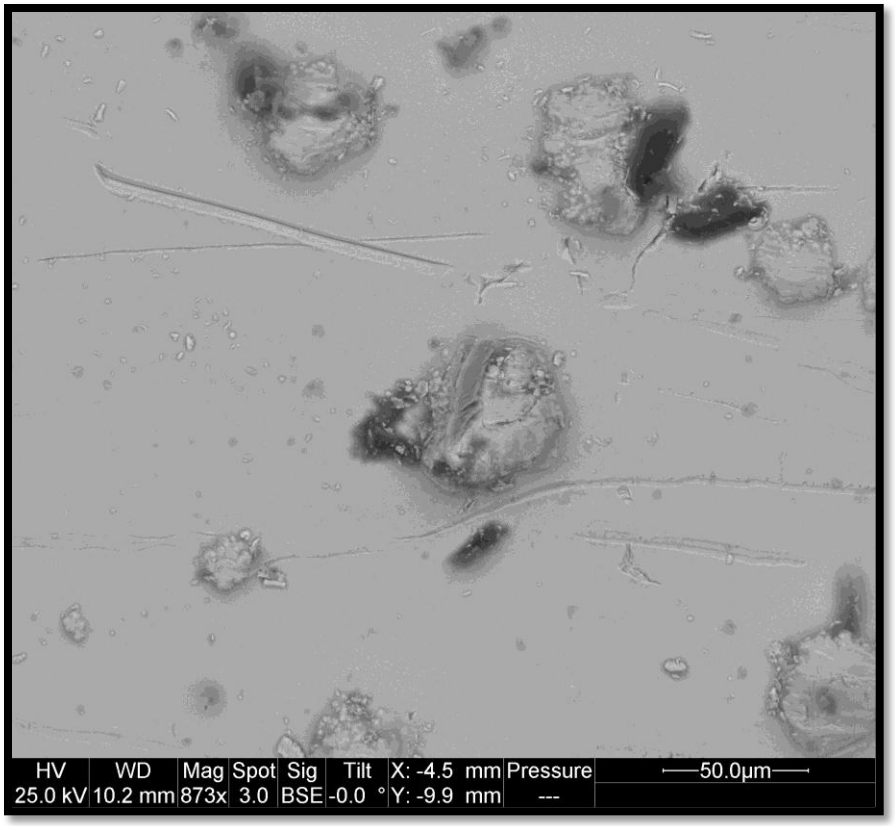

SE view – topographical image


Tin Whiskers in area with high density of ‘blisters’
HV
25.0 kV
WD
10.7 mm
Mag
100x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -16.4 mm
Y: -11.3 mm
Pressure
---
500.0µm

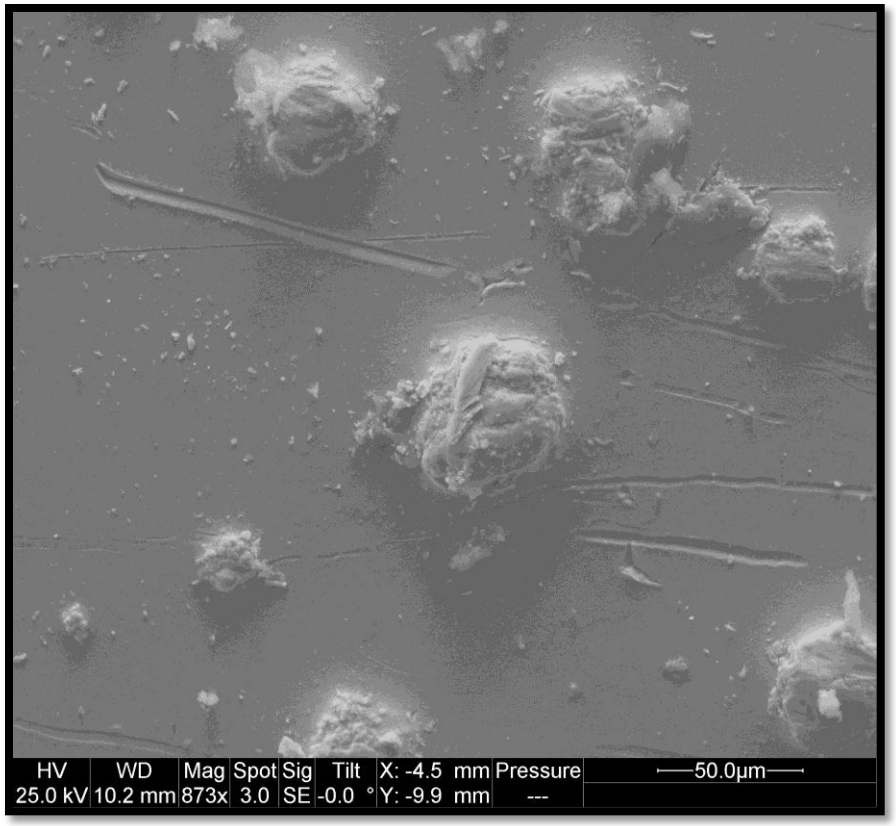

Tin Whisker
HV
25.0 kV
WD
10.7 mm
Mag
298x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -17.1 mm
Y: -11.2 mm
Pressure
---
200.0µm


Blistered Tin Coating
In "Blackened" Region
HV
25.0 kV
WD
10.2 mm
Mag
100x
Spot
3.0
Sig
SE
Tilt
-0.1 °
X: -4.5 mm
Y: -9.9 mm
Pressure
---
500.0µm

# Blistered Tin Coating In "Blackened" Region



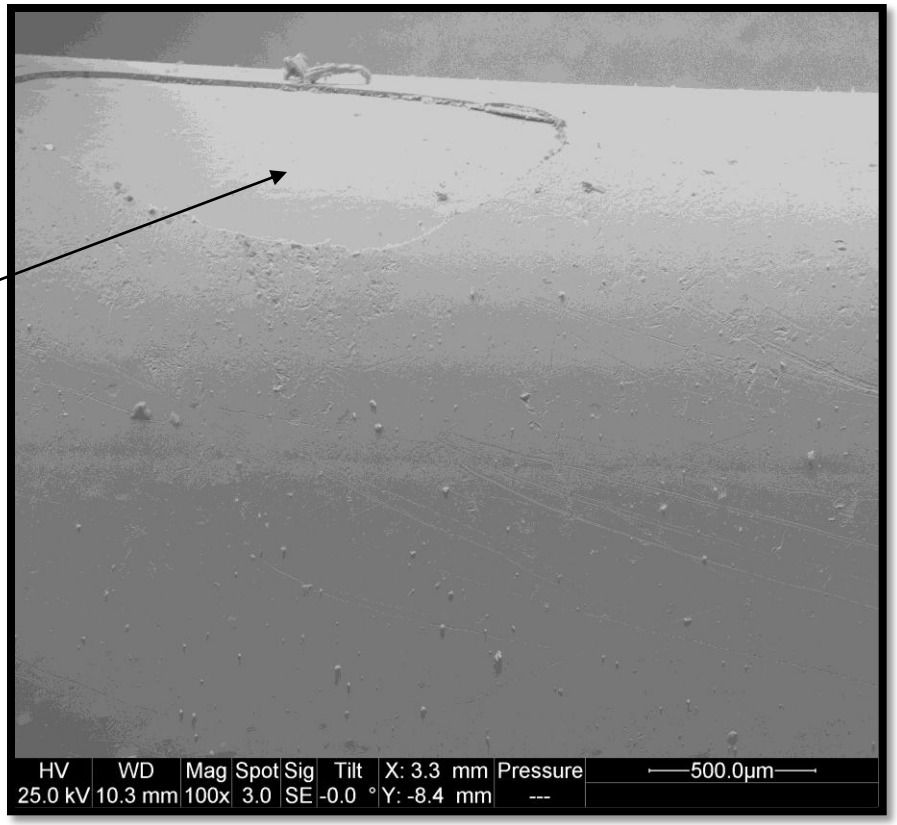

BSE view – difference in materials




SE view – topographical image

# Area with a piece of top tin coating flaked-off, and more tin exposed underneath

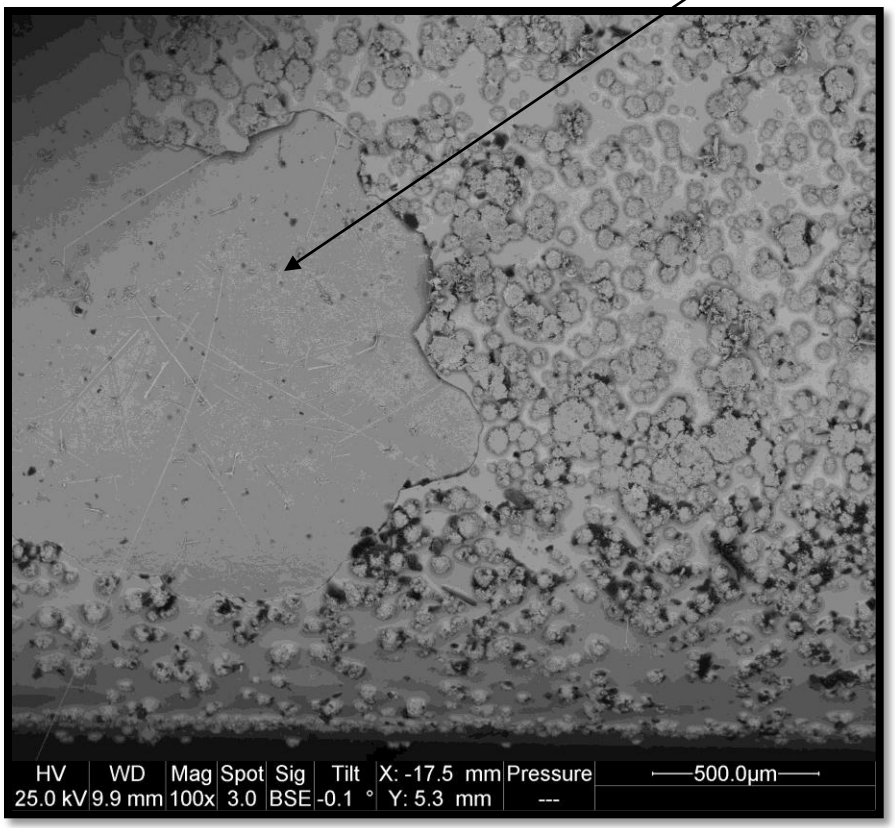

BSE view – difference in materials



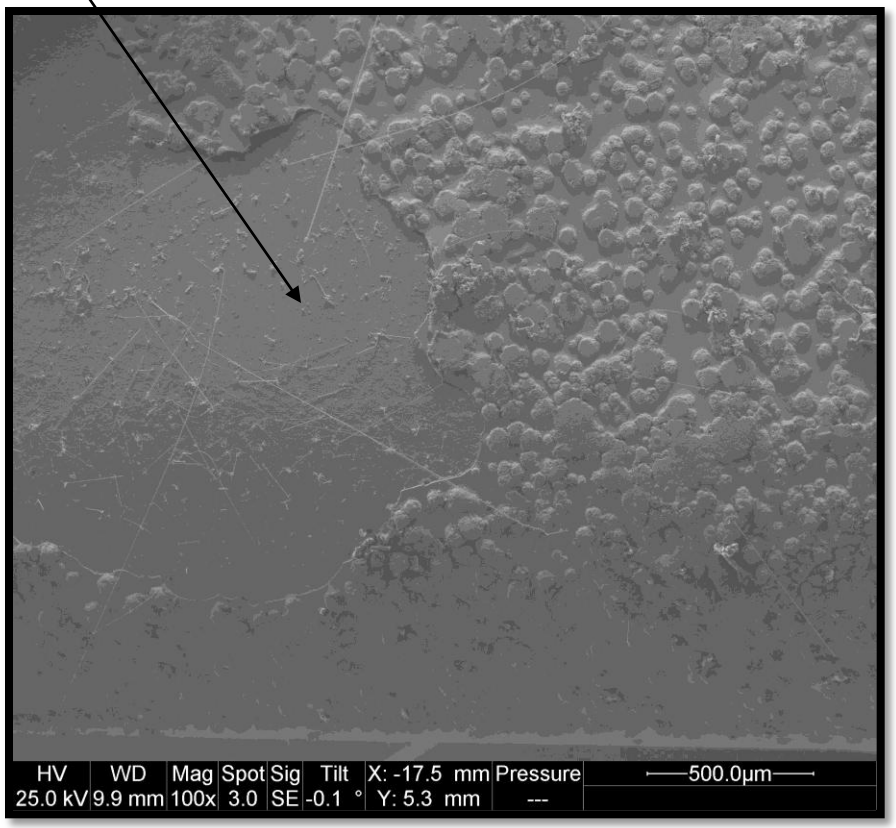

SE view – topographical image

# Tin Whiskers In "Blackened" Region of Bus Rail where Material has Flaked Off

Area of Sn exposed after flaking of top layer



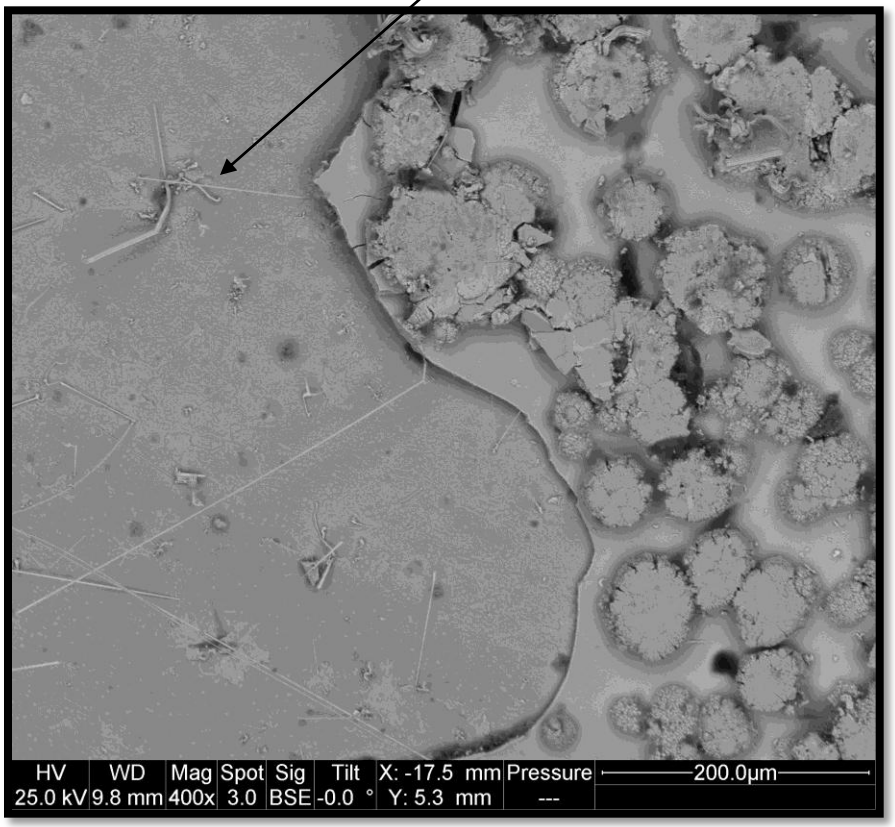

BSE view – difference in materials



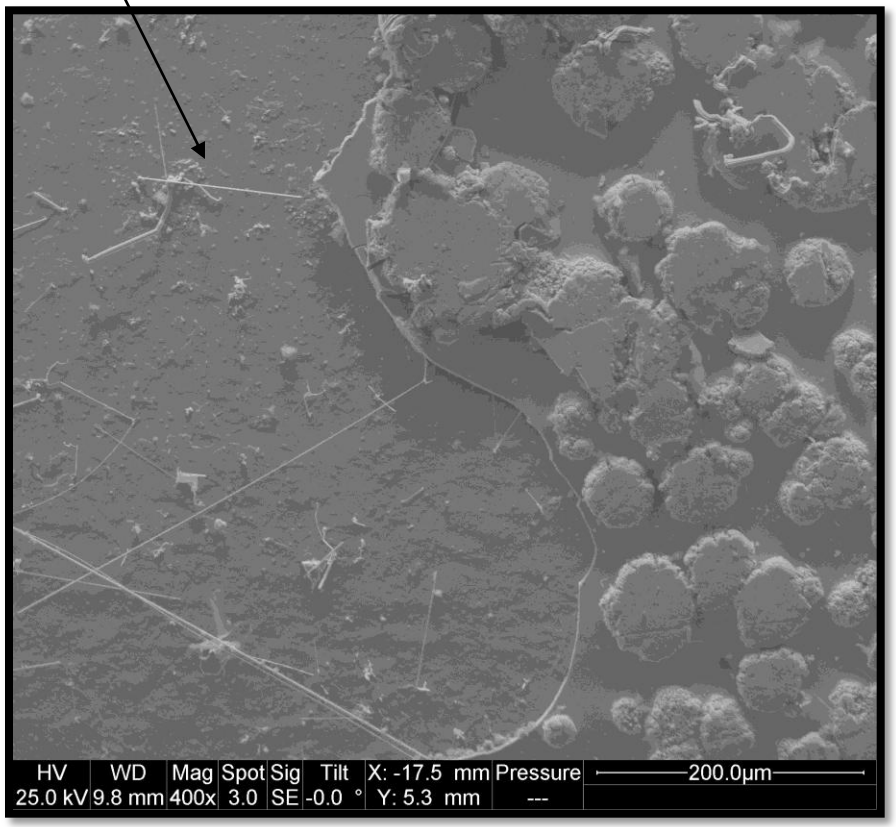

SE view – topographical image

# Tin Whiskers In "Blackened" Region of Bus Rail where Material has Flaked Off

Area of Sn exposed after flaking of top layer

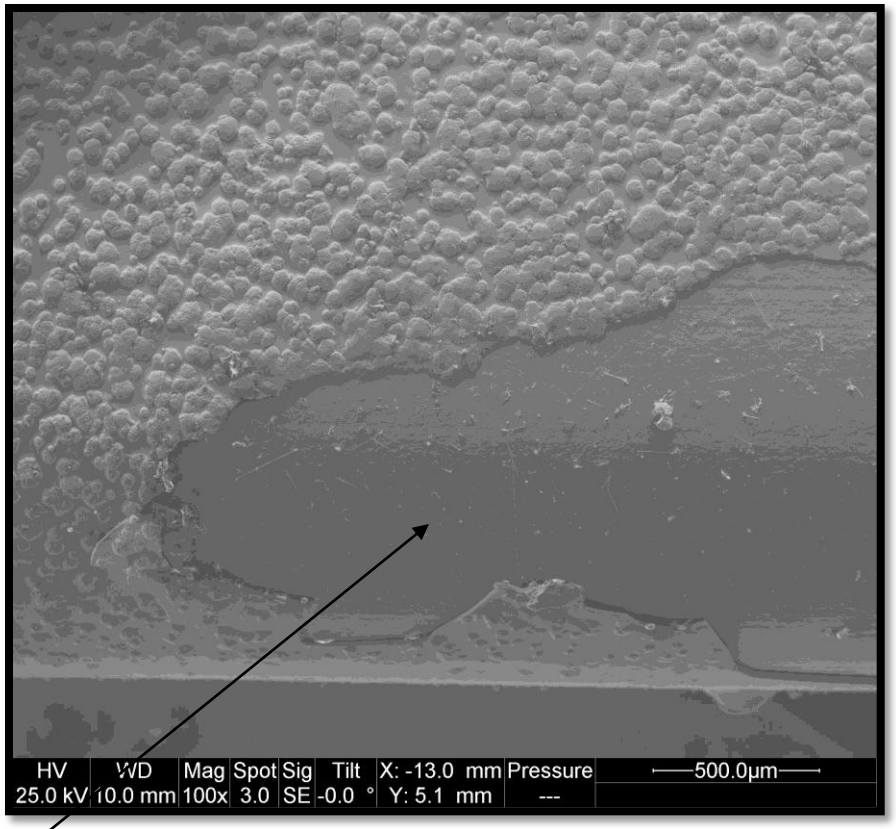



BSE view – difference in materials




SE view – topographical image

# "Blackened" Region of Bus Rail where Material has Flaked Off

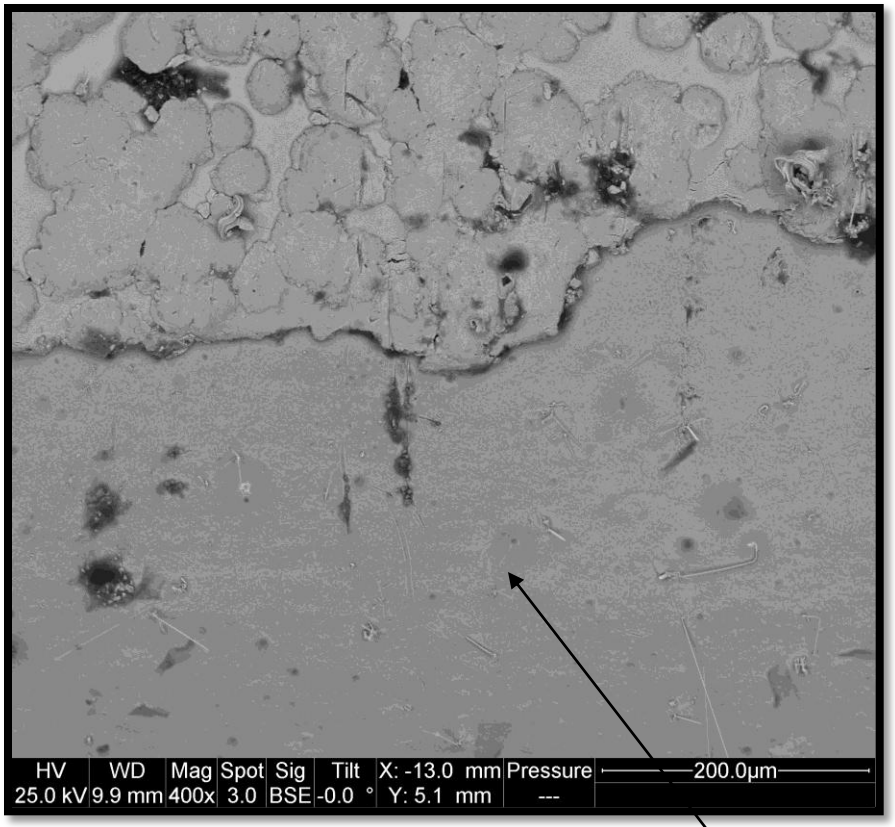



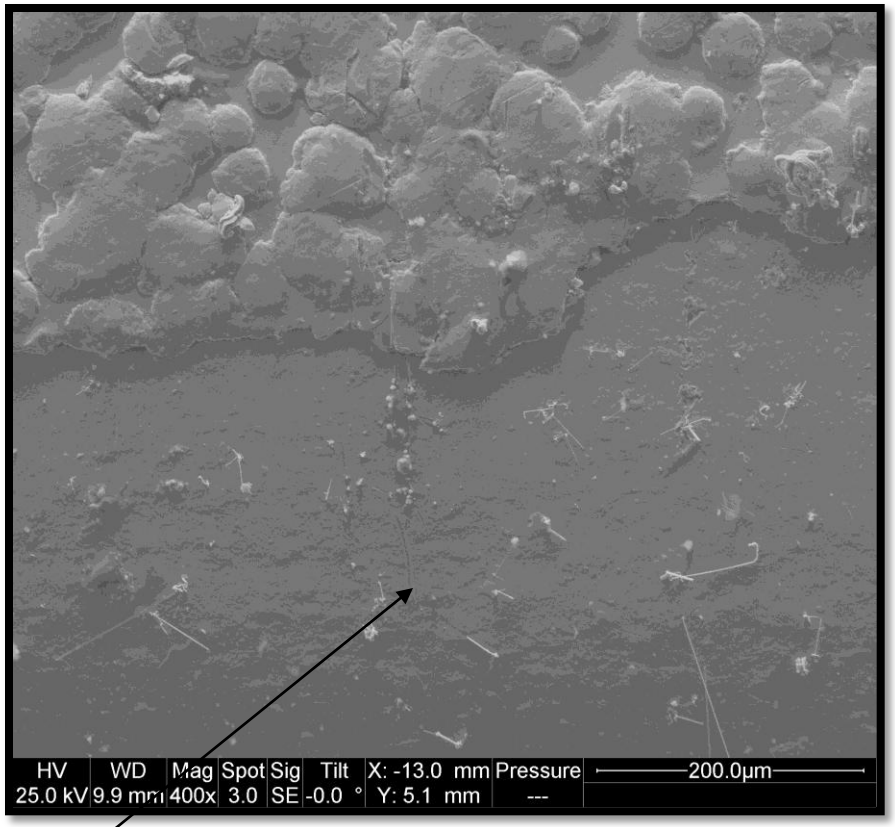

Area of Sn exposed after flaking of top layer

BSE view – difference in materials

SE view – topographical image

# "Blackened" Region of Bus Rail where Material has Flaked Off

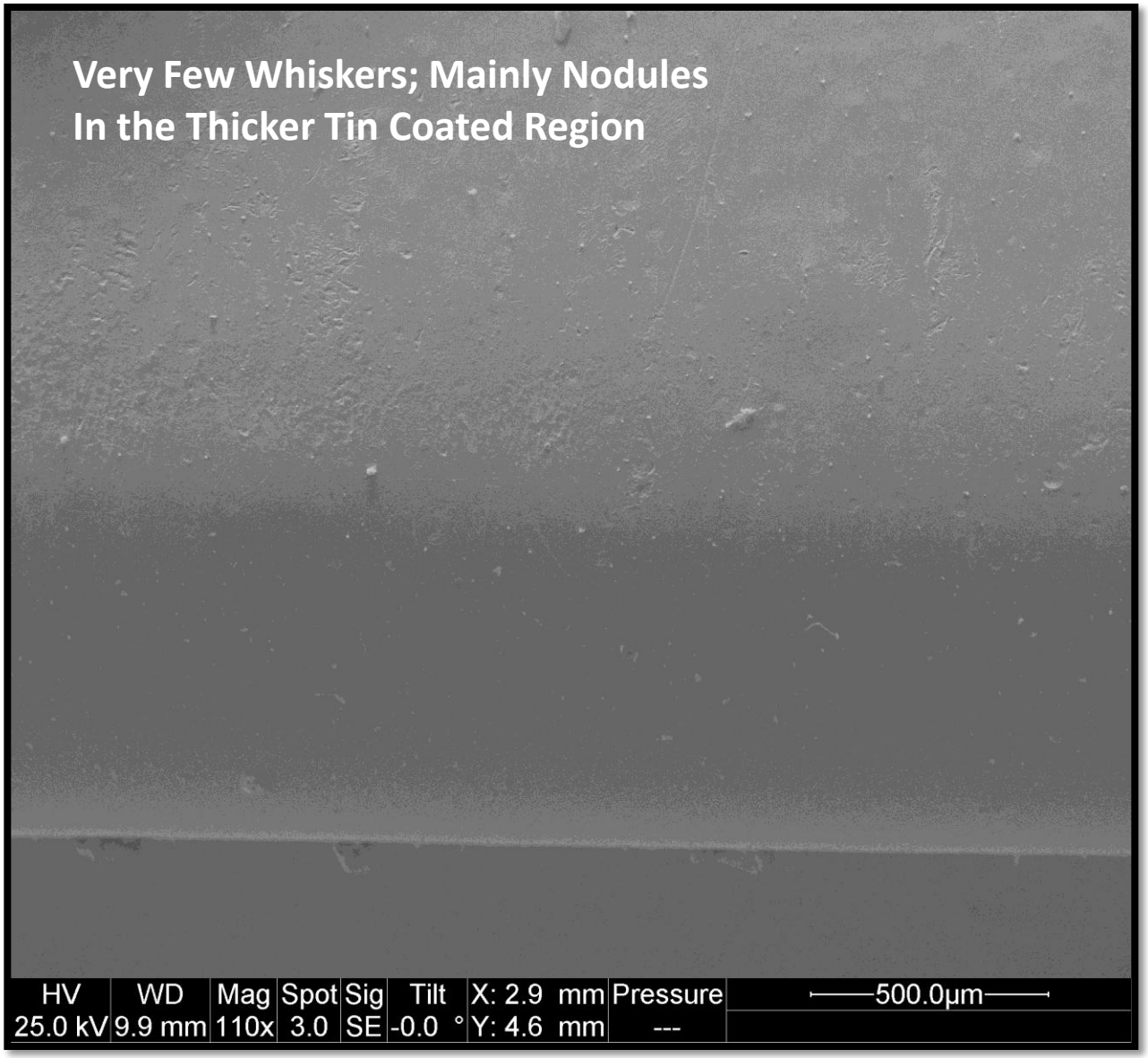



Area of Sn exposed after flaking of top layer

BSE view – difference in materials

SE view – topographical image


Very Few Whiskers; Mainly Nodules
In the Thicker Tin Coated Region
HV 25.0 kV
WD 9.9 mm
Mag 110x
Spot 3.0
Sig SE
Tilt -0.0 °
X: 2.9 mm Y: 4.6 mm
Pressure ---
500.0µm

# Contact Information

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Acknowledgment:

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