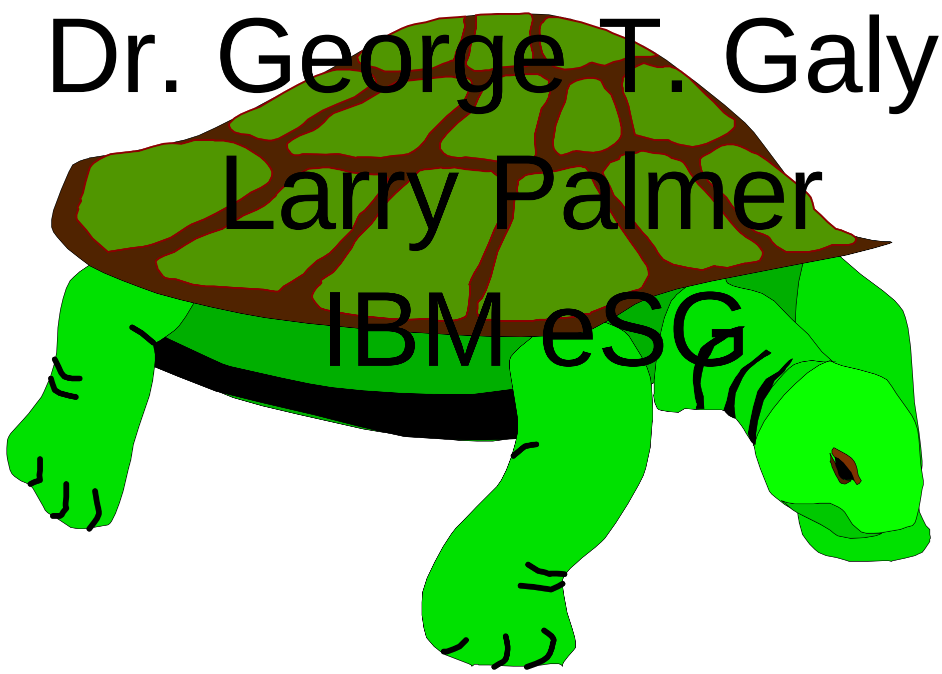
Tin Whisker Microstructural Analysis

Dr. George T. Galyon

Larry Palmer

IBM eSG



Whisker Theories

- Dislocations
  - Axial Screw Disloc.-M.Peach
  - Prismatic Loops
    - Eshelby(1st), Franks, Lindborg, Lee & Lee
  - Rotating Edge Dislocs.
    - F.C. Frank(1st)
    - W.C. Ellis, et al.
- Climbing Helices-Amelinckx et al.
- Recrystallization
  - W. C. Ellis (1st)
  - T. Kakeshita, et al.
  - V.K. Glazunova and N.T. Kudryavtsev
- Cracked Oxide
  - K.N. Tu (1st)
  - Lee and Lee
  - Chen Xu

Ideas concerning the mechanism of the process include
epresentations of the structure of the deposits, but in
nost cases these are not confirmed by experiment. To
btain grounds for the proposed schemes of the process
nechanism, it would be useful to have data on the fine
tructure of the tin lattice. This would give a clearer
epresentation of the mechanism of action of the forces
eading to "repulsion" of the monomer crystal from the
ulk of the coating. At present (1985) the role of
islocations in this mechanism has not been generally
ecognized".

.M. Gorbunova and V.K. Glazunova, Present State of
ne Problem of Spontaneous Growth of Whisker Crystals
n Electrolytic Coatings, translated from Zaschita
letallov, Vol. 20, No. 3, May-June 1984, p 342-358.

Koonce-Arnold: 1953

-Whiskers grow from the addition of material to the bottom of the whisker and not from the addition of material to the growing tip.

Fisher, Darken, and Carroll: 1954

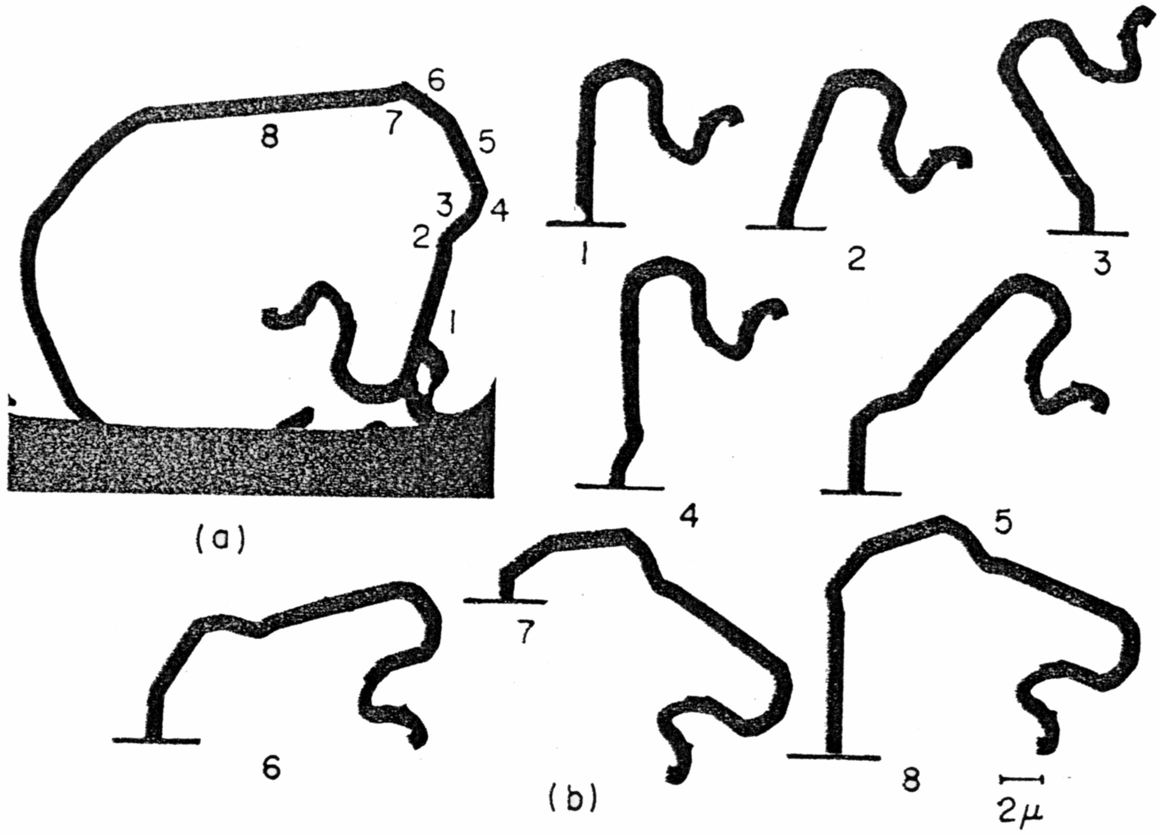
-Whiskers form and grow under the influence of compressive stress gradients

W.C. Ellis, et al.: 1958

- Not all whisker growth directions are low-indice glide planes...dislocation theories are not relevant to (at least) these non-glide plane growth directions.

Sn whiskers grown on inside of drilled and polished Sn-Al cast alloy

N. Furuta & K. Hamamura, Jap. J.Appl.Phys. 8(1969) 1404



courtesy: M. Boettinger-NIST

H.P. Kehrer and H.G. Kadereit:1970

Whisker material comes from the plating / substrate interface

U. Lindborg: 1976

Bulk Diffusion cannot sustain the observed whisker growth rates.

W.J. Choi, T.Y. Lee, & K.N. Tu:2002

micro-diffraction X-Ray shows compressive stress gradients around whisker

W. Stevens-Brookhaven: 2002

synchrotron X-Ray analysis showed vertical compressive stress gradients in tin films ~ 40 MPas

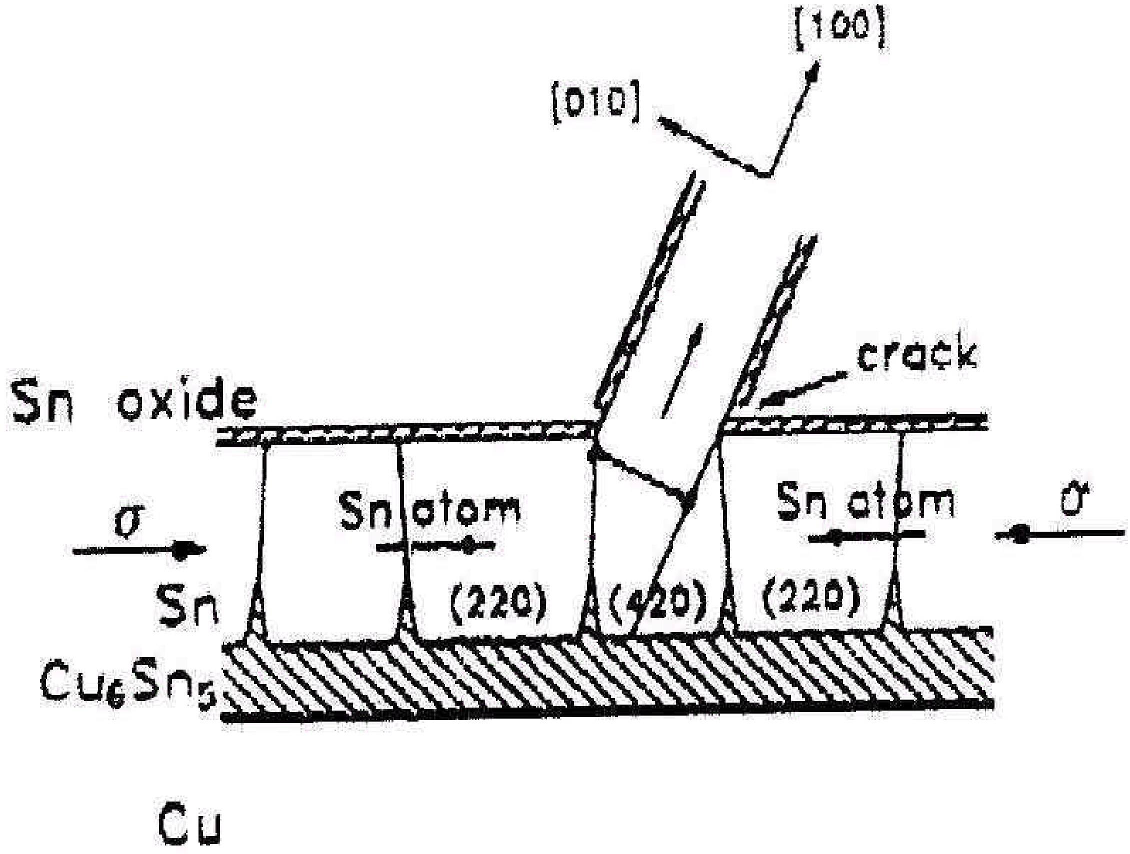


Fig. 19. Sketch of glide of expanded prismatic dislocation loop.

ref. Lee and Lee, Acta Met., 1998

Integrated recrystallization theory-elements of
G. T. Galyon / L. Palmer-eSG IBM

1. **whiskers/nodules do not grow from as-plated structures.**

2. **A localized recrystallization event precedes whisker/nodule formation.**

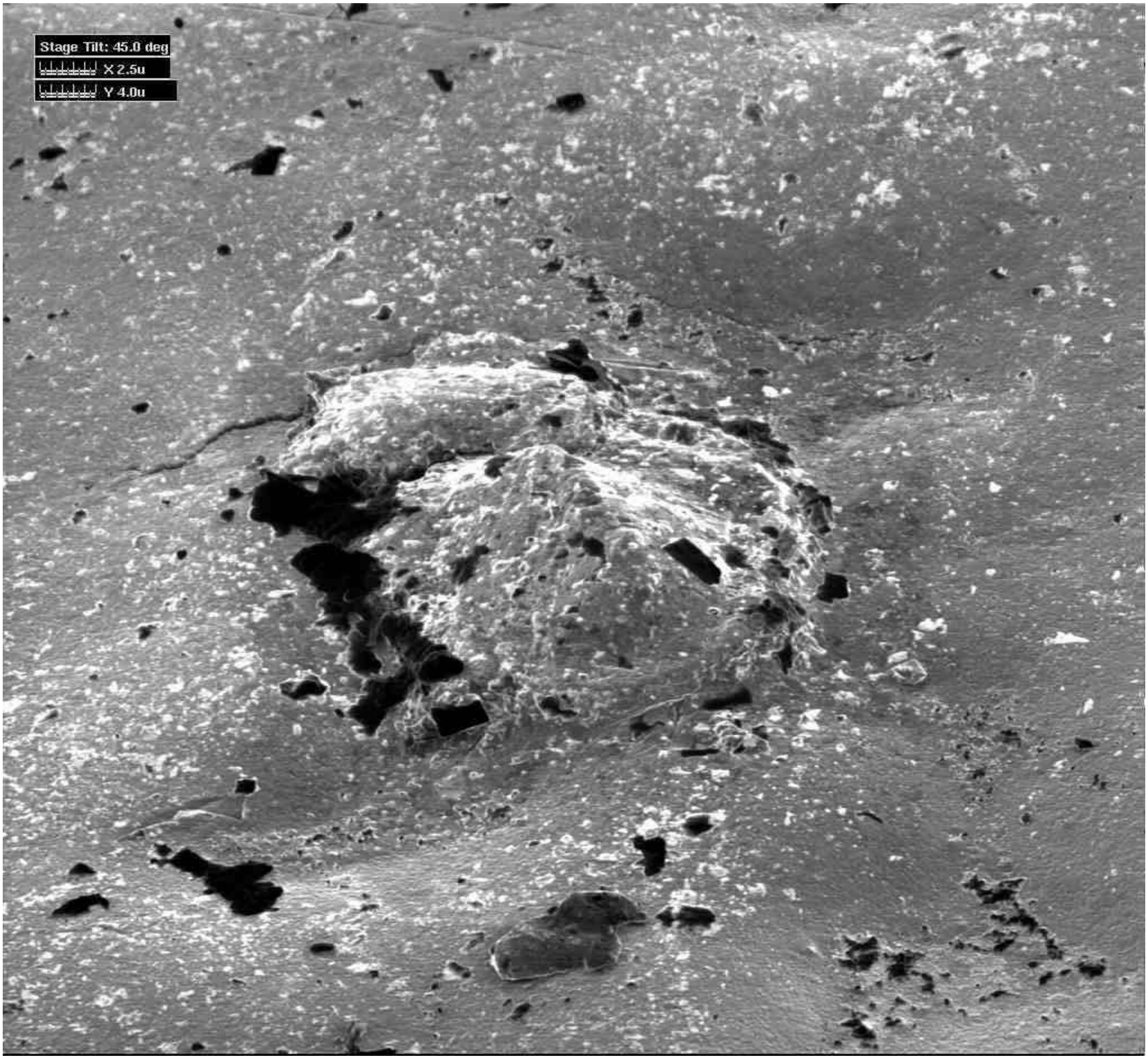
3. **The recrystallized region is a region of lower average stress re the surrounding region**

4. **If the surrounding region is more compressively stressed-a whisker/nodule may form.**

5. **A whisker/nodule may erupt thru the surface layer if the oxide is not too thick.**

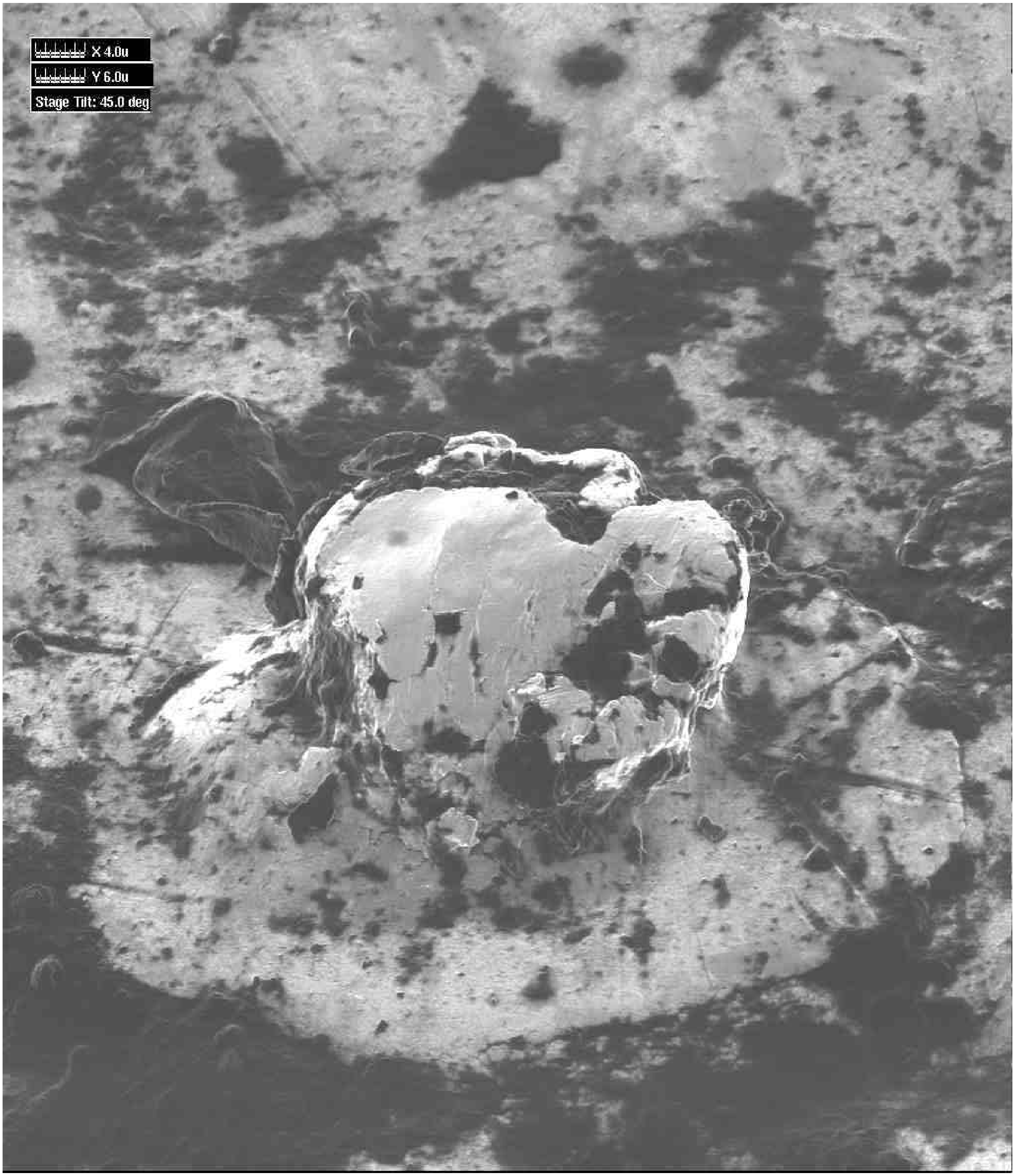
6. **A whisker, or filament, is a special case of nodule growth.**

7. **The whisker/nodule material comes mainly from the surrounding regions thru the grain boundries-principally from the plating/ substrate interface.**

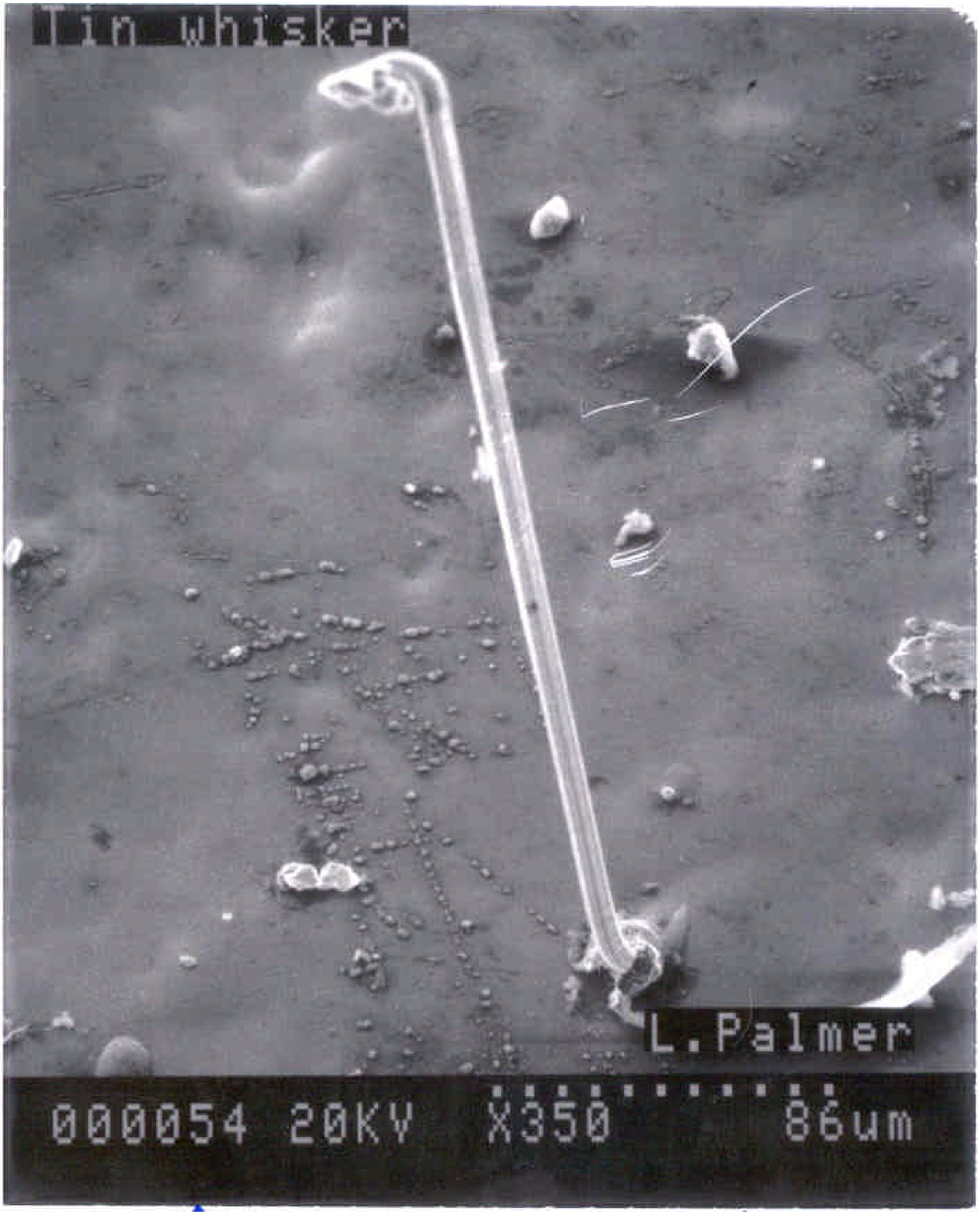


bright-tin surface mound (Sn over Cu)

o note crack in upper left quadrant of mound

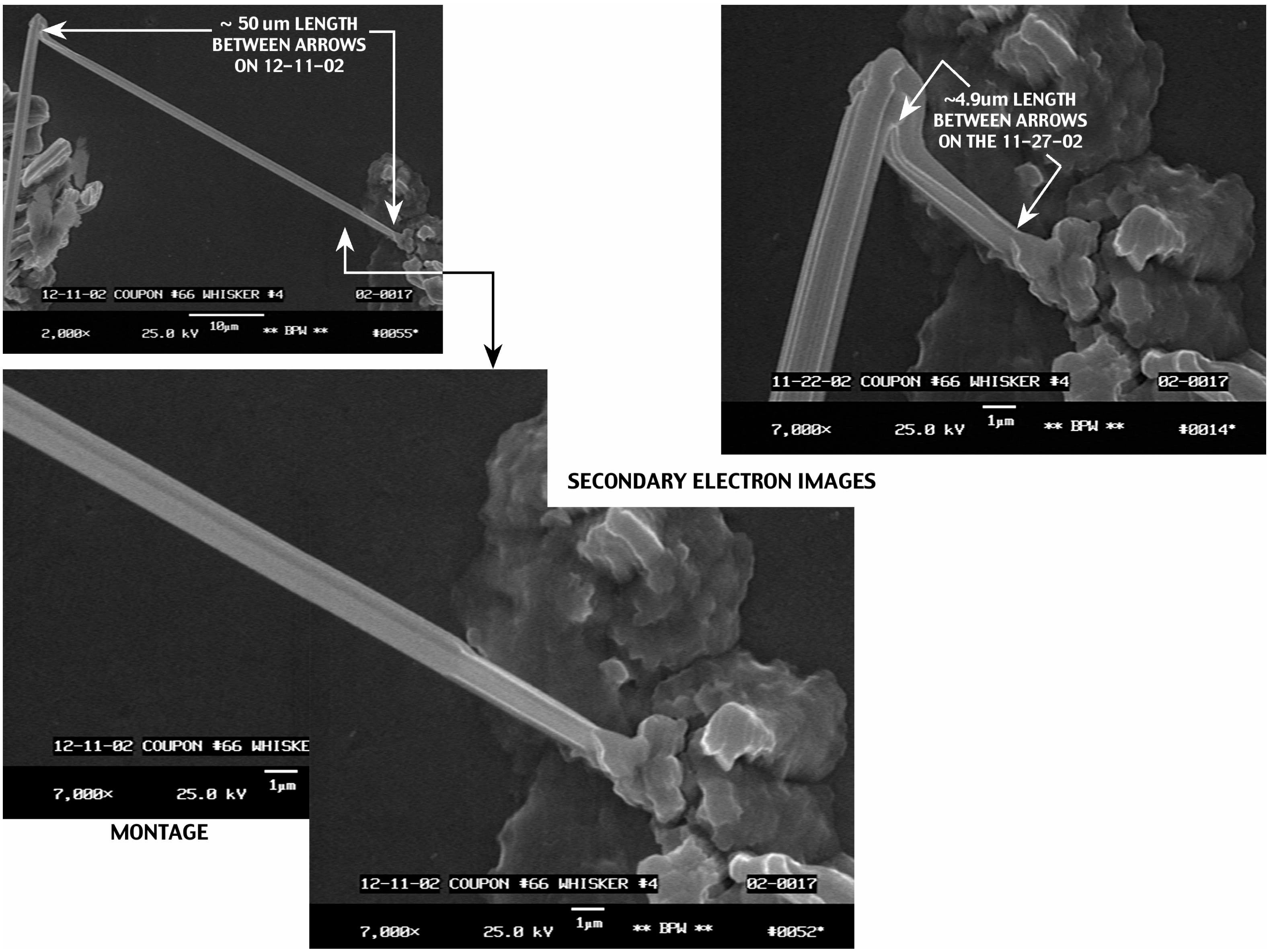


bright-tin surface eruption (Sn over Cu)

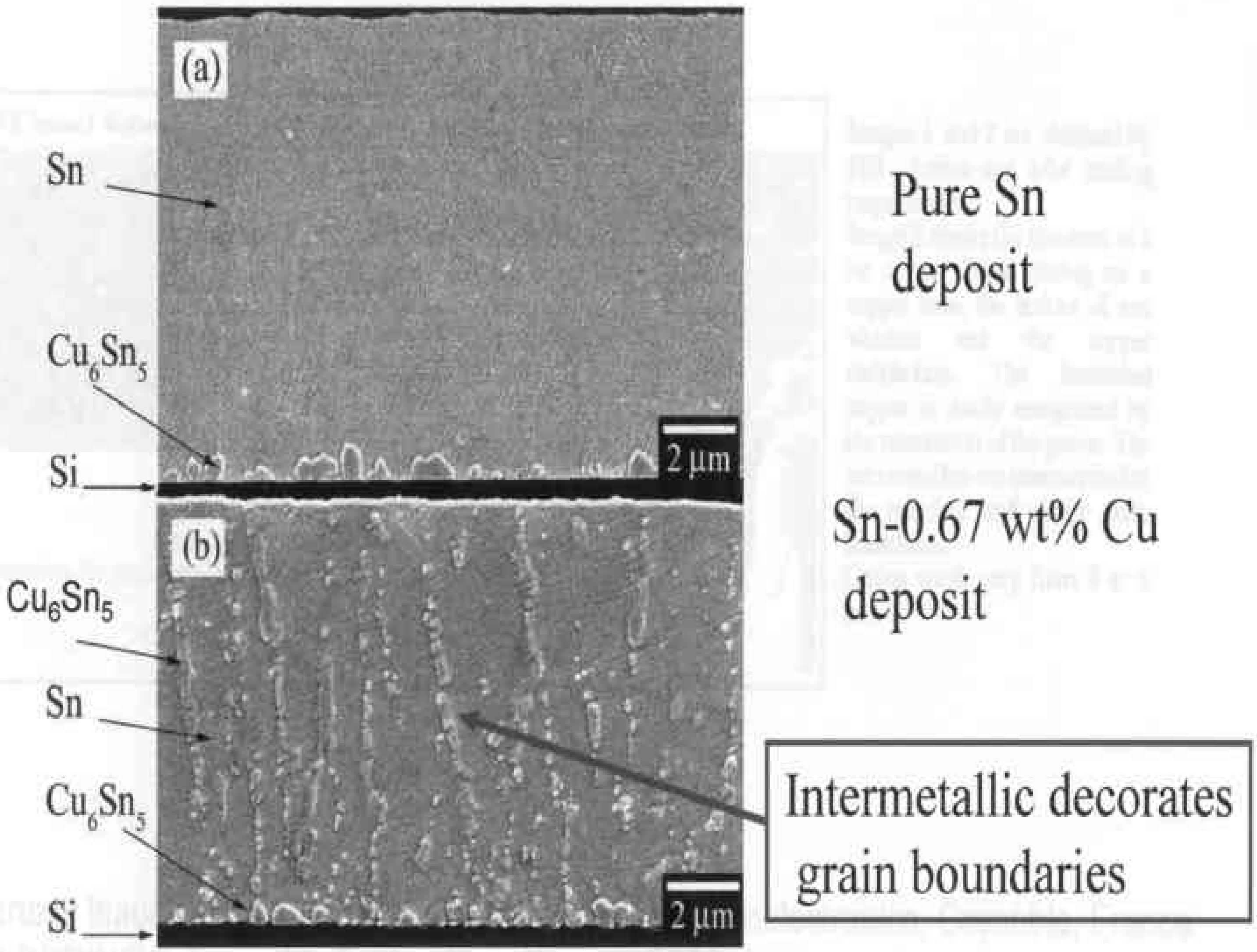


Bright Tin: SEM micrograph (Sn over Cu)

Field service whisker-approx. 250u long

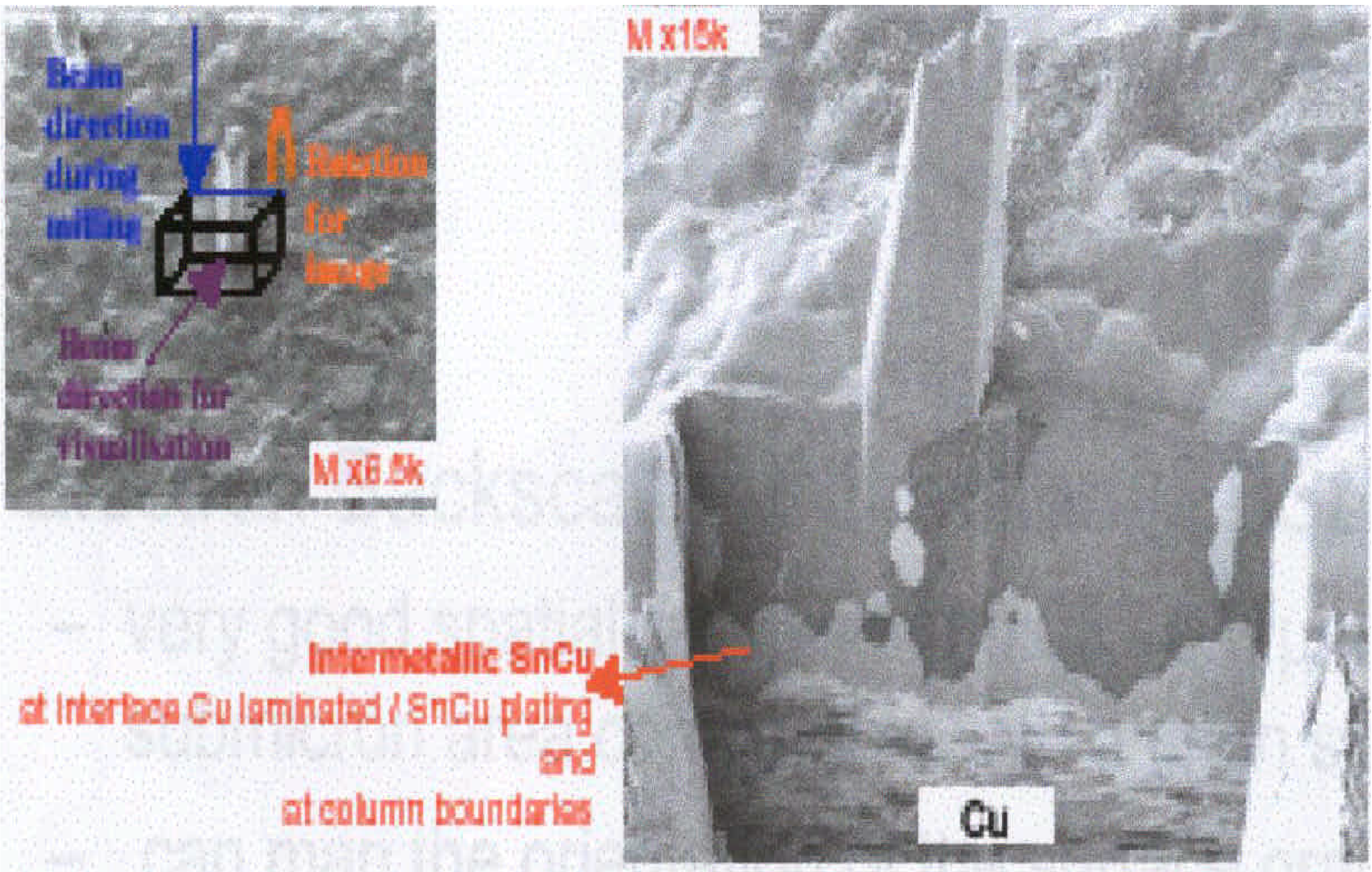


courtesy Dr. Thomas A. Woodrow-Boeing Corp.



courtesy of M. Wiliams, C.E. Johnson, K. Moon, G.R. Stafford, C. Handwerker, W. Boettinger: NIST

o Optical micrograph of bright tin plating (unetched)

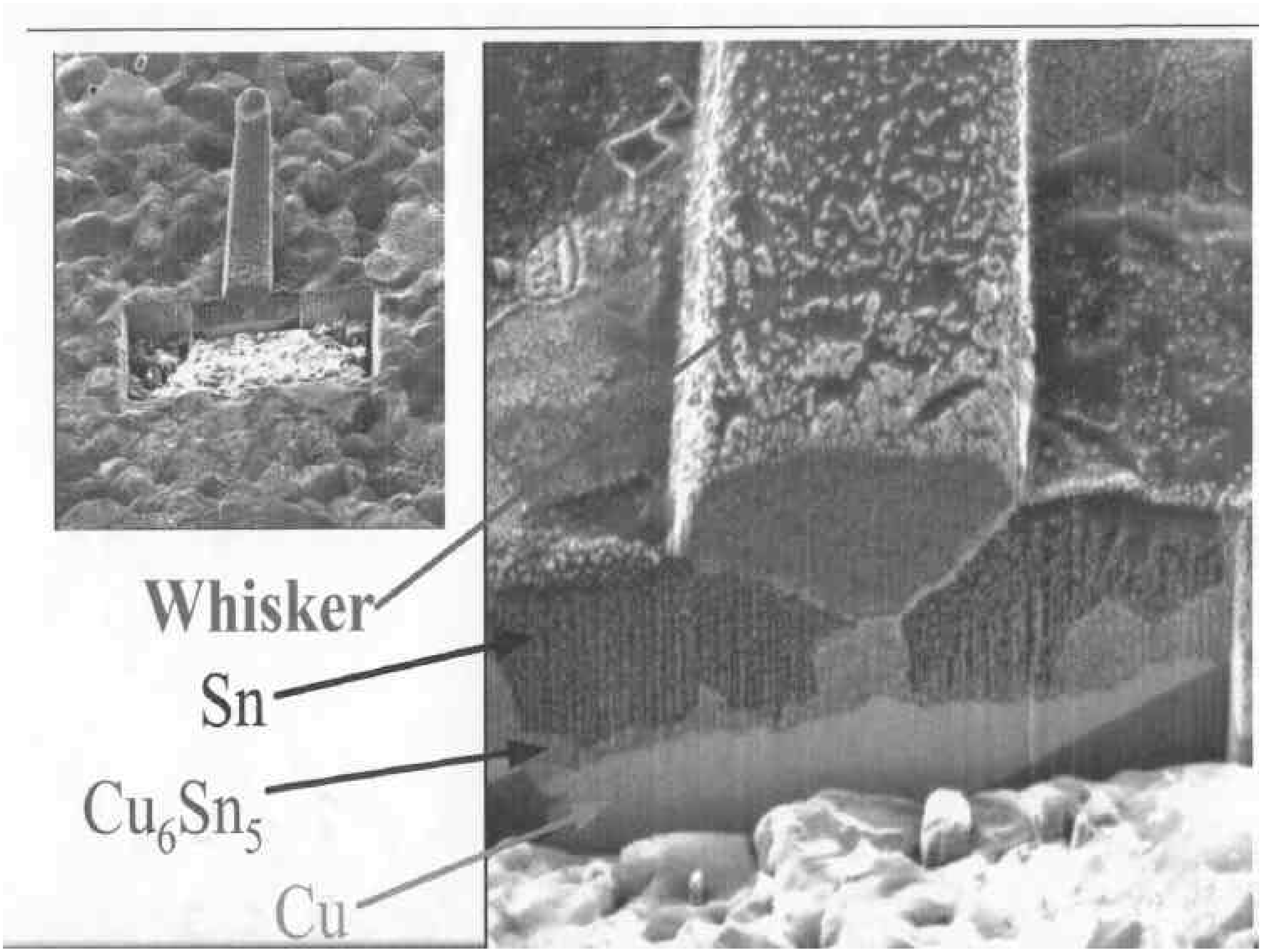


courtesy: Baudry and Kerros, ST Microelectronics

The first published FIB micrograph of Sn plating showing a cross-section of whisker/plating/IMC/ substrate.

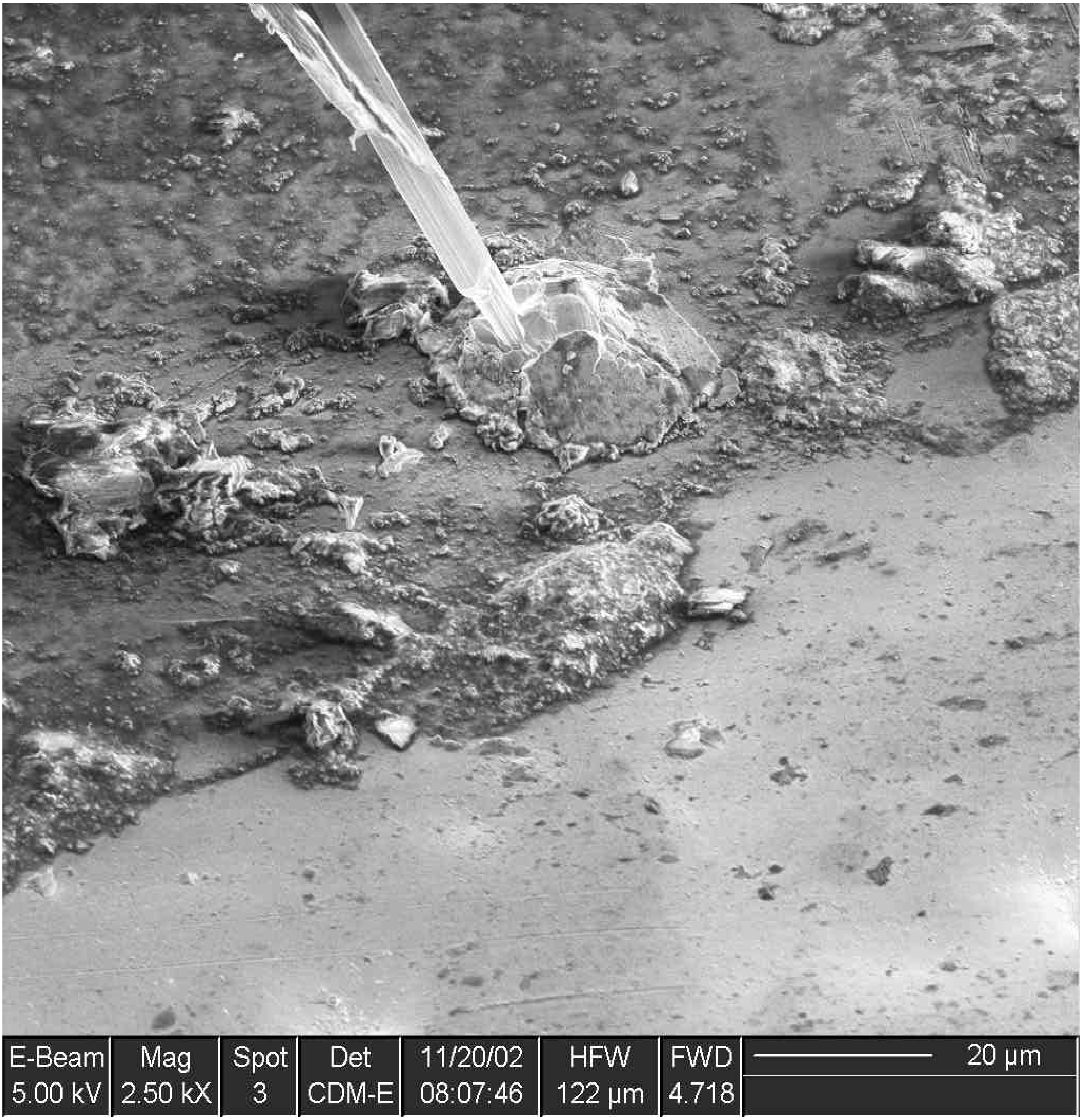
Plating type not identified (matte/bright)

Note IMC nodule at root of whisker



courtesy: Chen Xu, Cookson Electronics

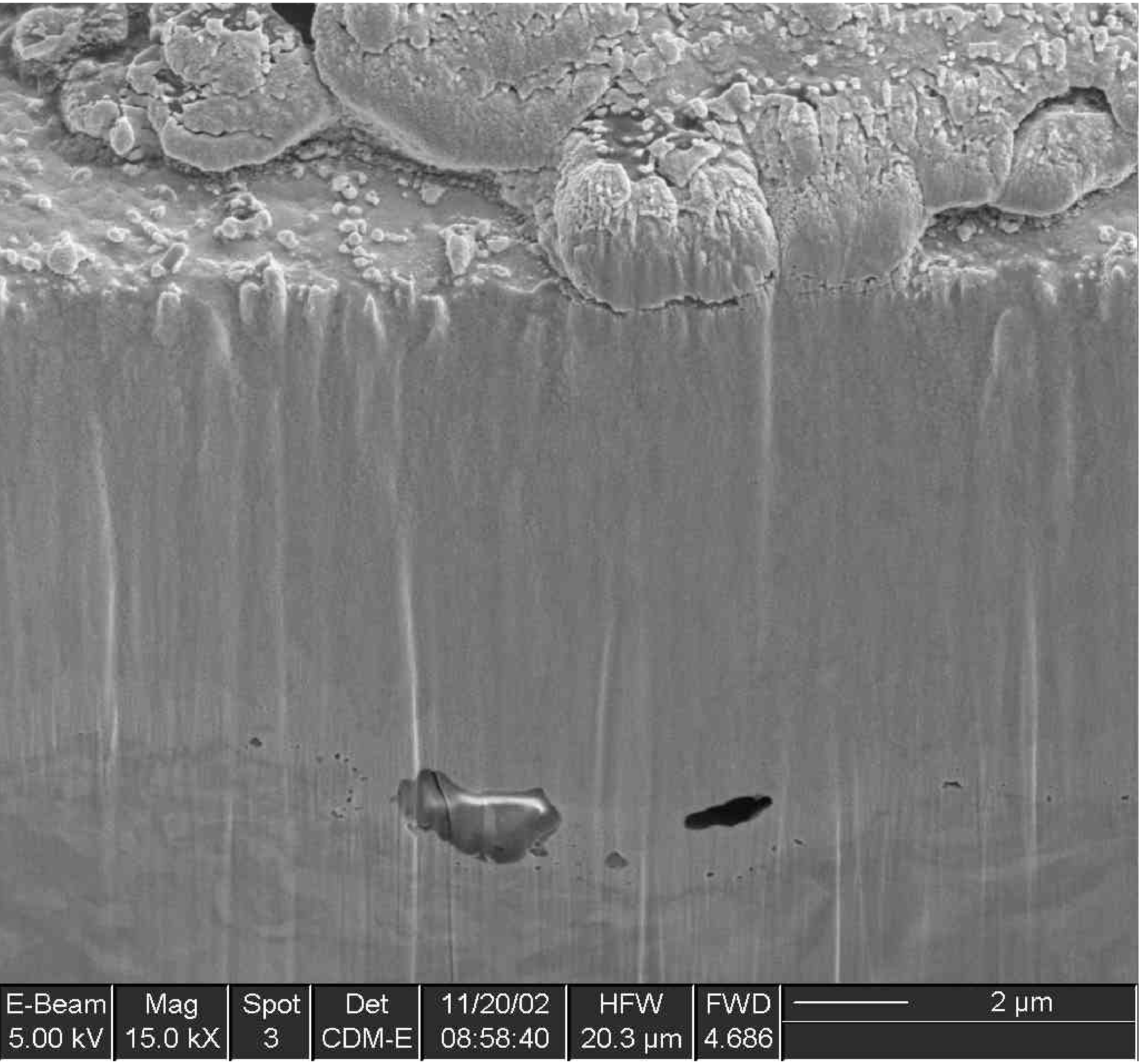
Note IMC particle at root of whisker



417-01

Bright Tin: Whisker eruption with "sleeving"

"sleeving" identified as CuSnx (Cu_6Sn_5?)

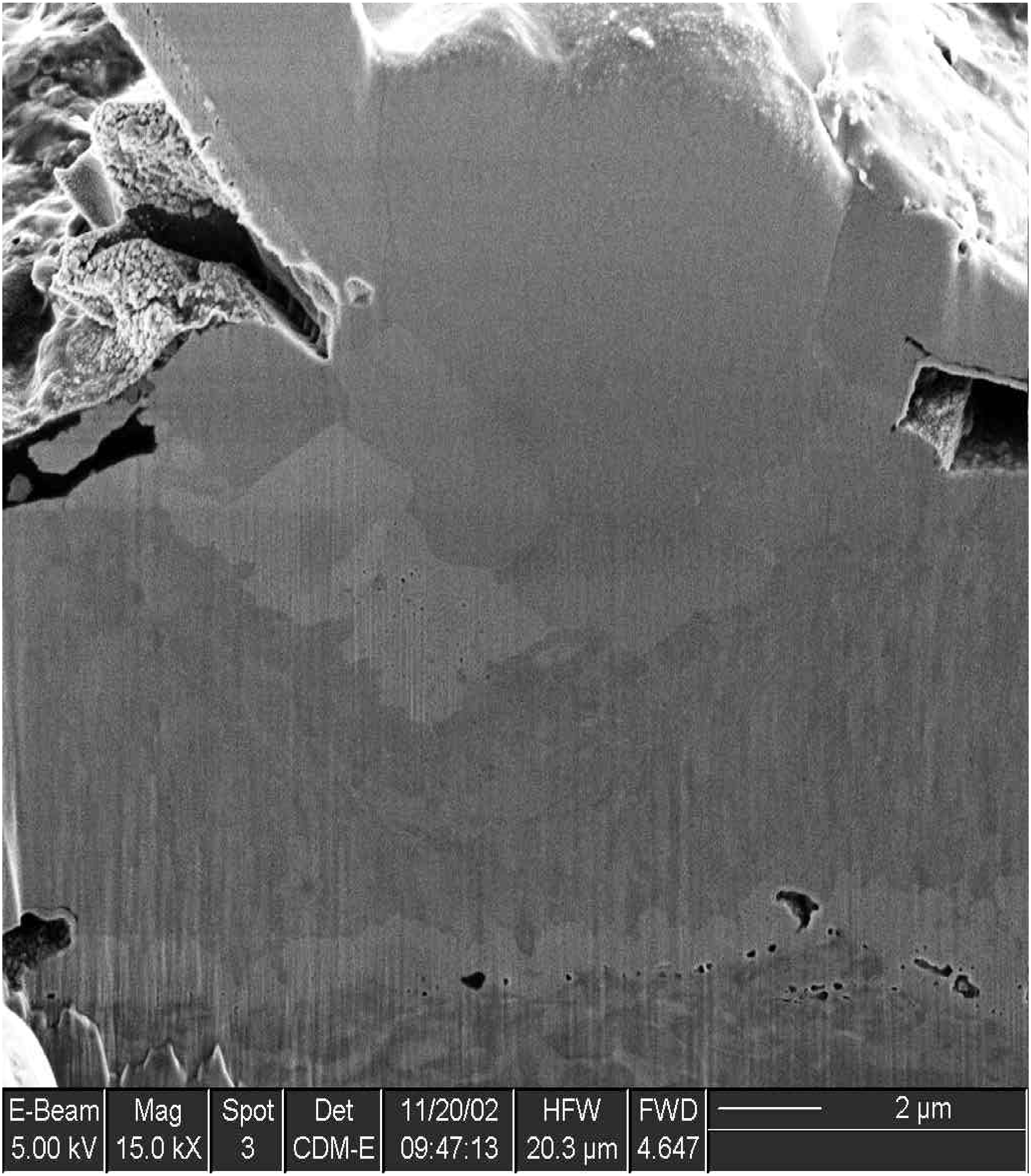


417-02

Bright tin: FIB cross-section / SEM micrograph

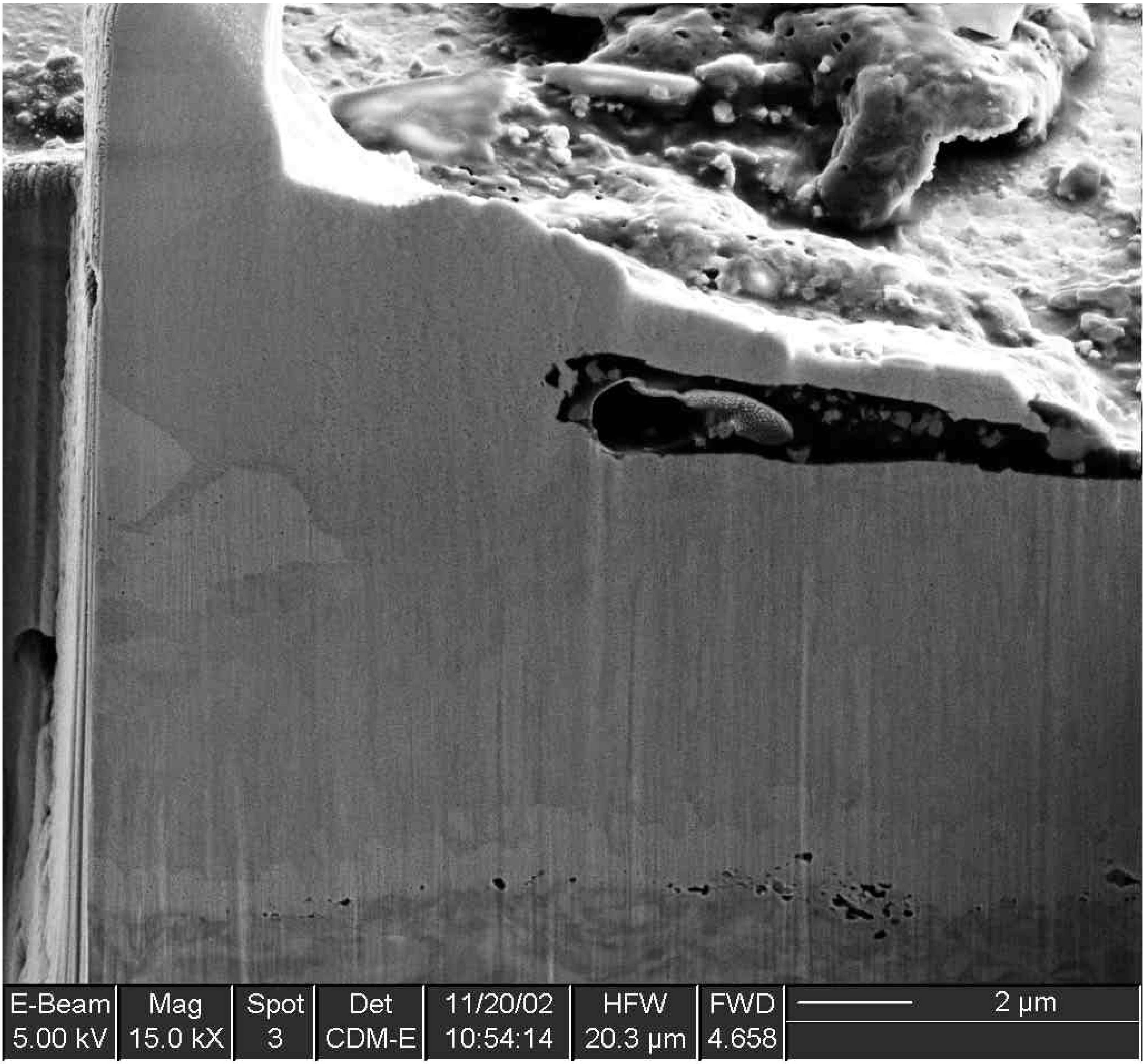
Cross-section outside of whisker-nodule region

Note "voids" at Sn/Cu interface



417-08

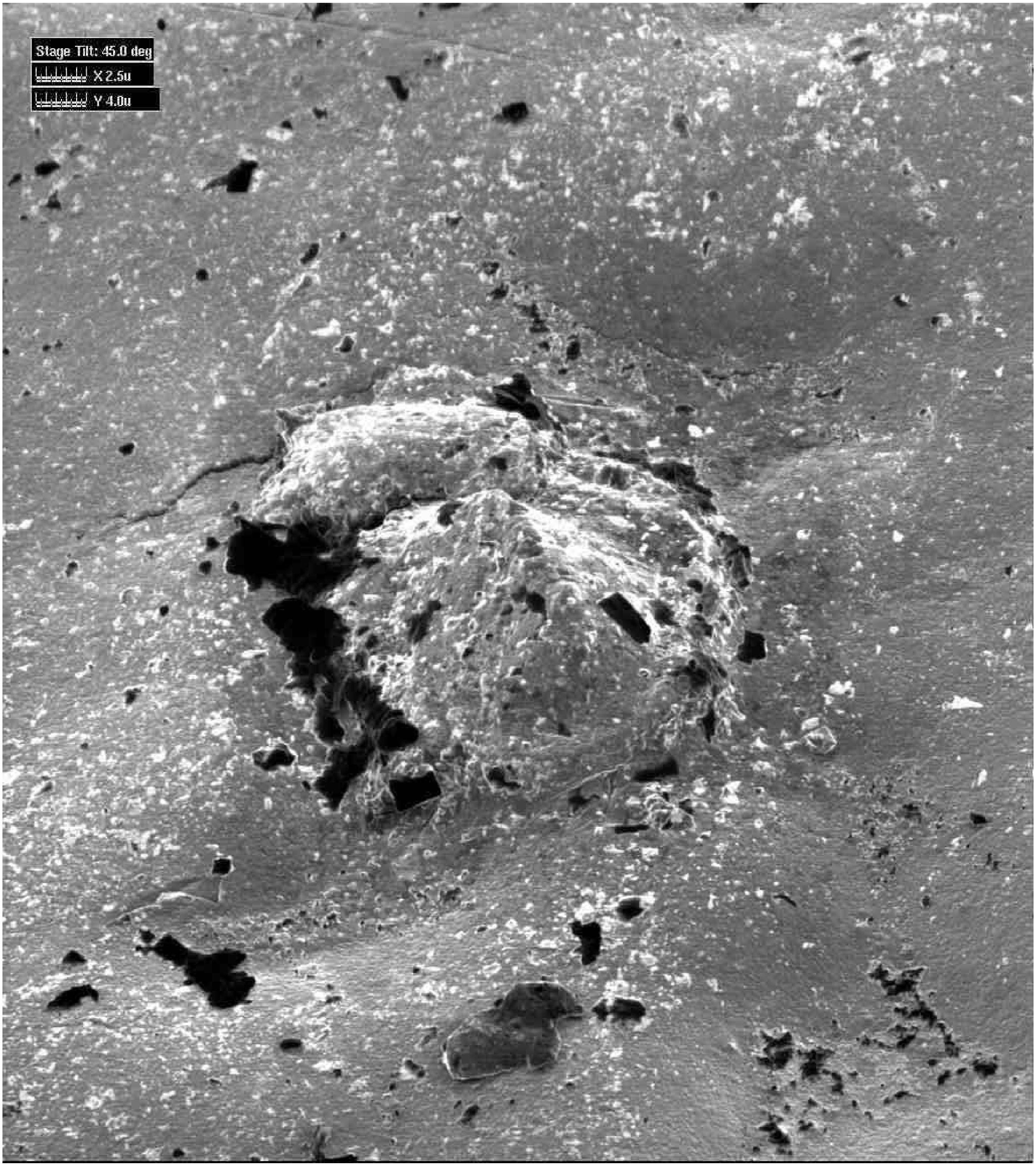
Bright Tin: FIB cross-section / SEM micrograph cross-section in whisker-nodule region



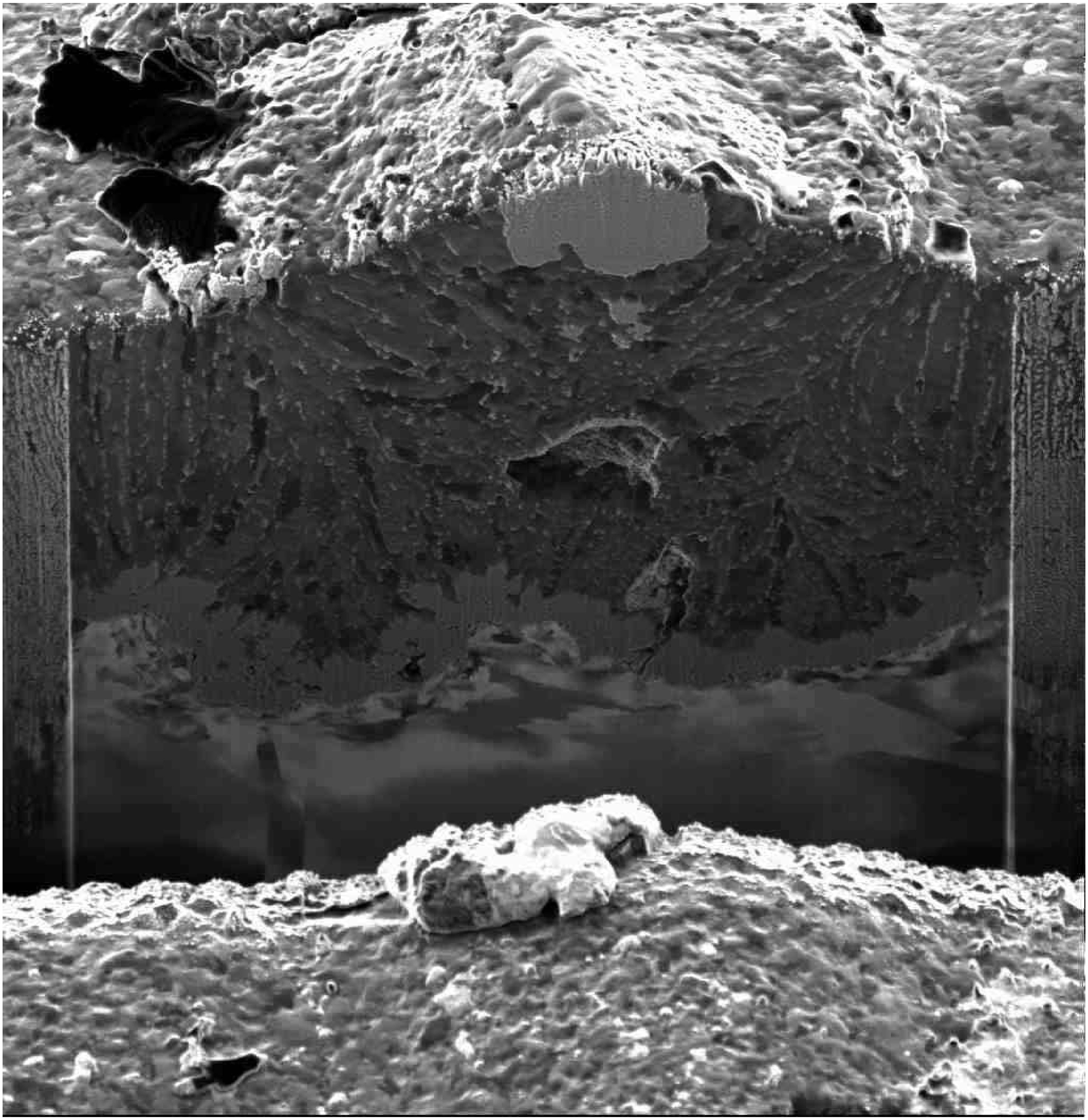
417-16

Bright Tin: FIB cross-section / SEM micrograph

cross-section moving thru whisker-nodule
Note: "flap" of CuSnx under nodule

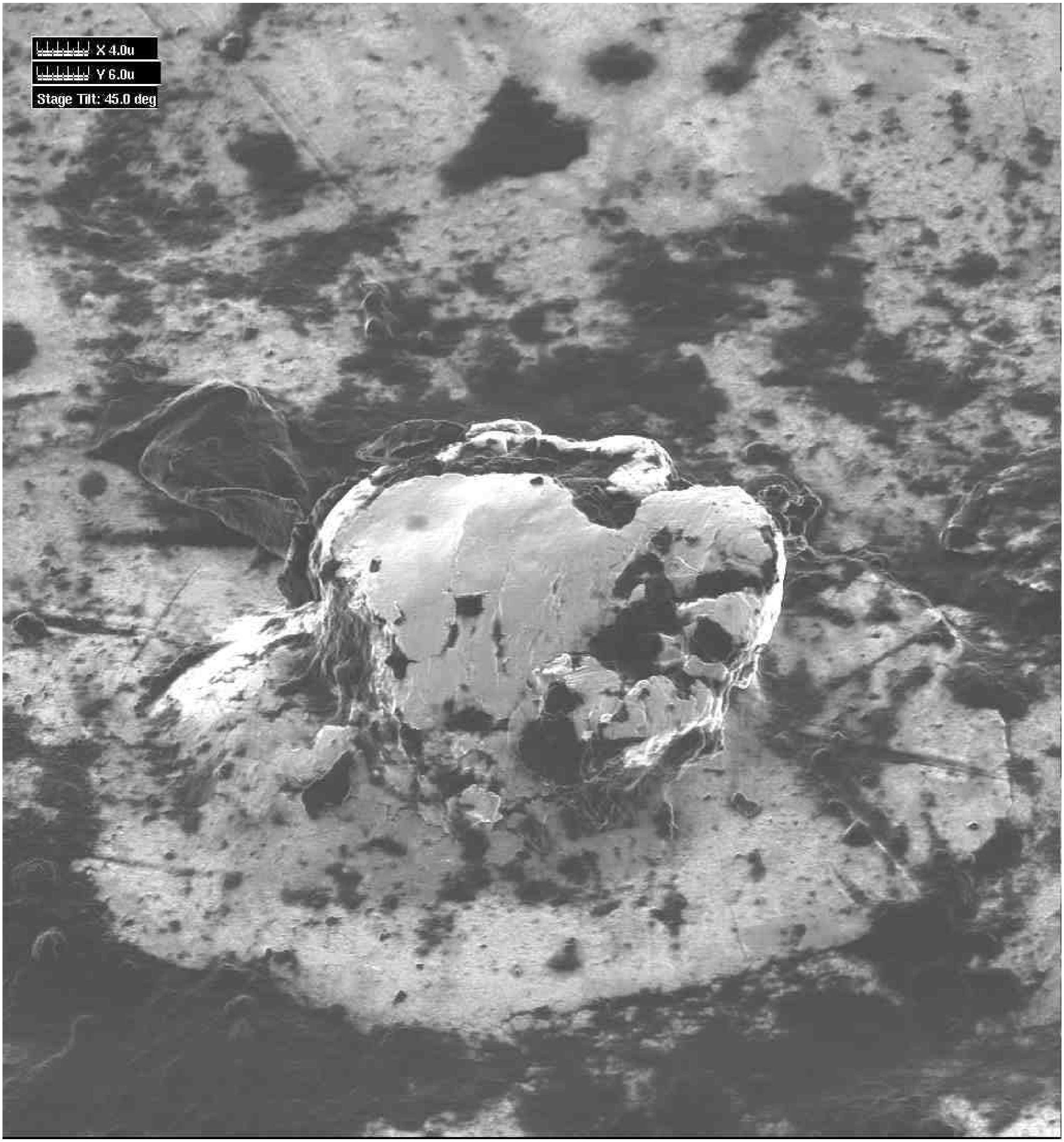


Bright Tin Growth Bump or Mound -45 deg. FIB

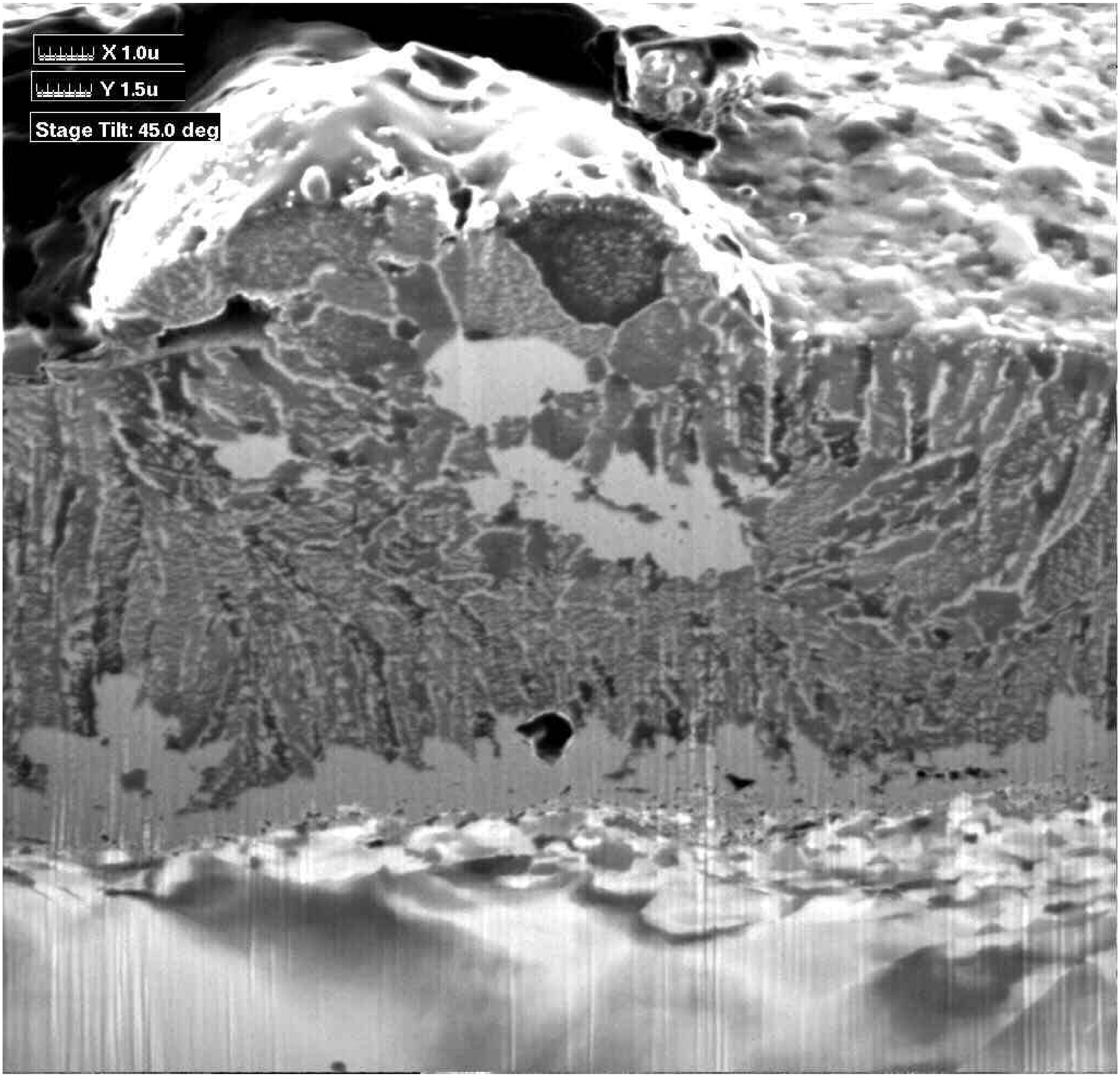


FIBs cross-section: bright tin "mound"

- inclusions in plated structure are CuSnx
- Tin plating is over copper substrate
- Cu_6Sn_5 intermetallic **particle at Sn/Cu interface**



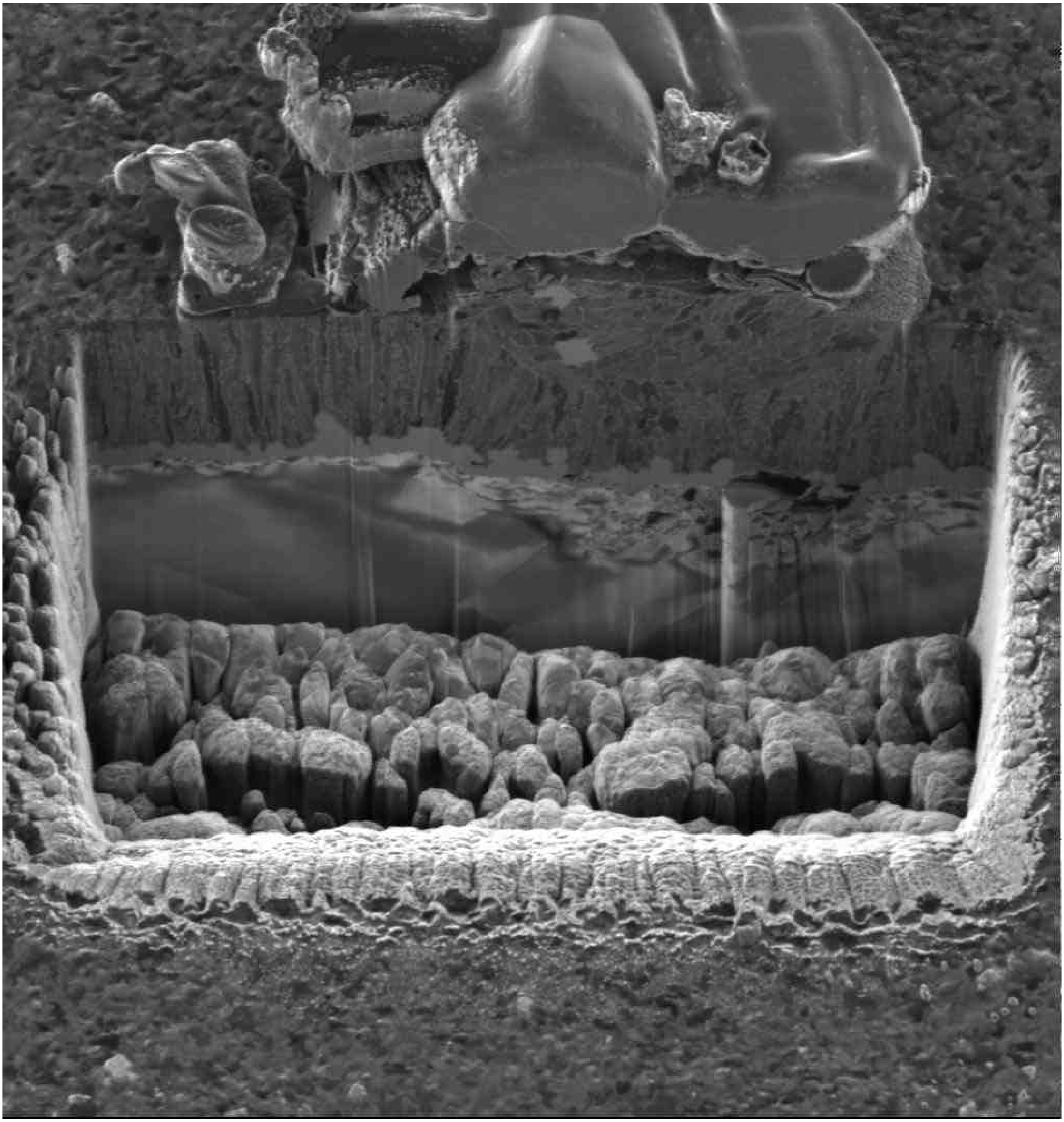
Bright tin nodule-20020417FIBC......



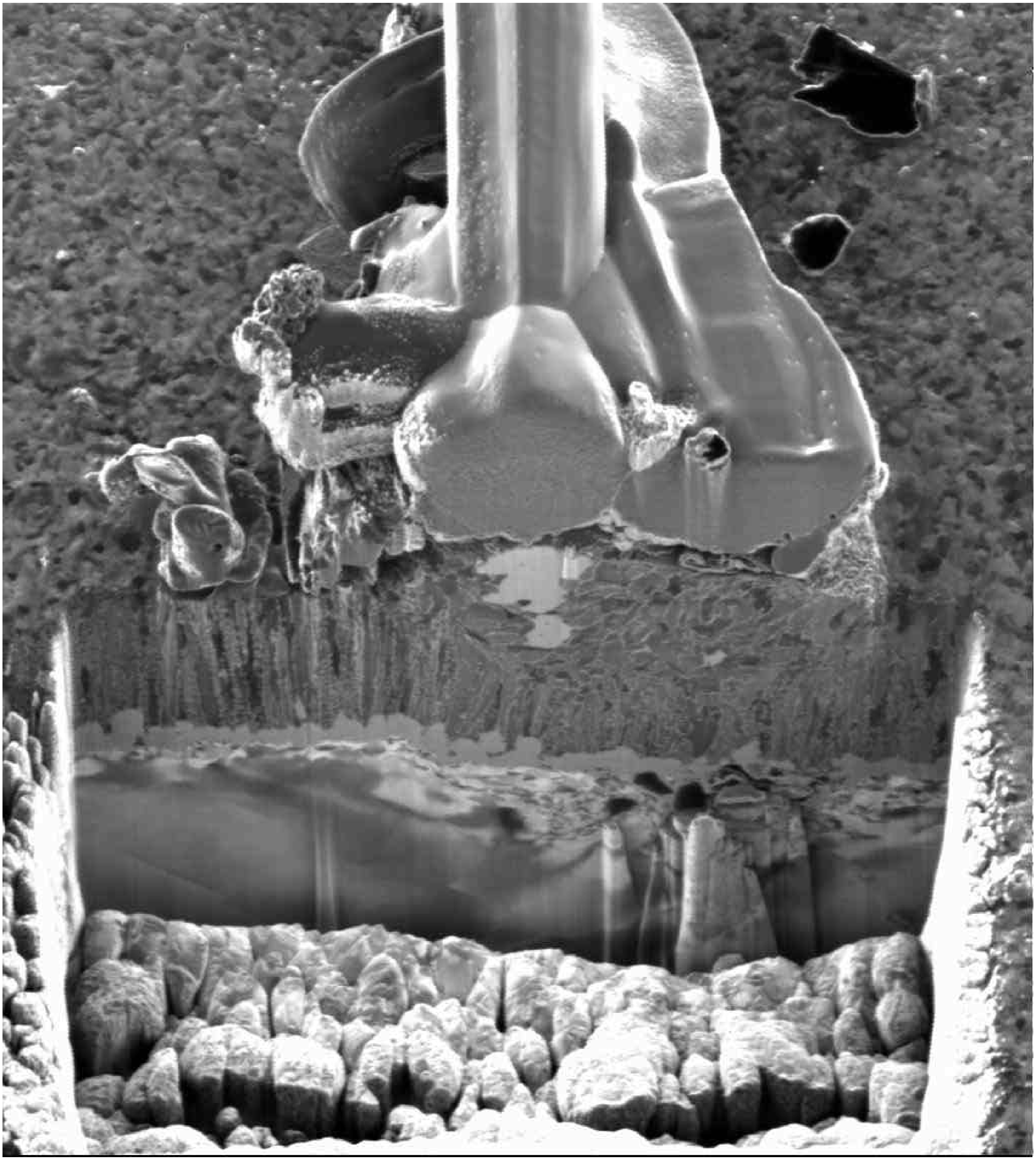
#0-16

Bright tin noudle: FIB cross-section/FIB micrograph

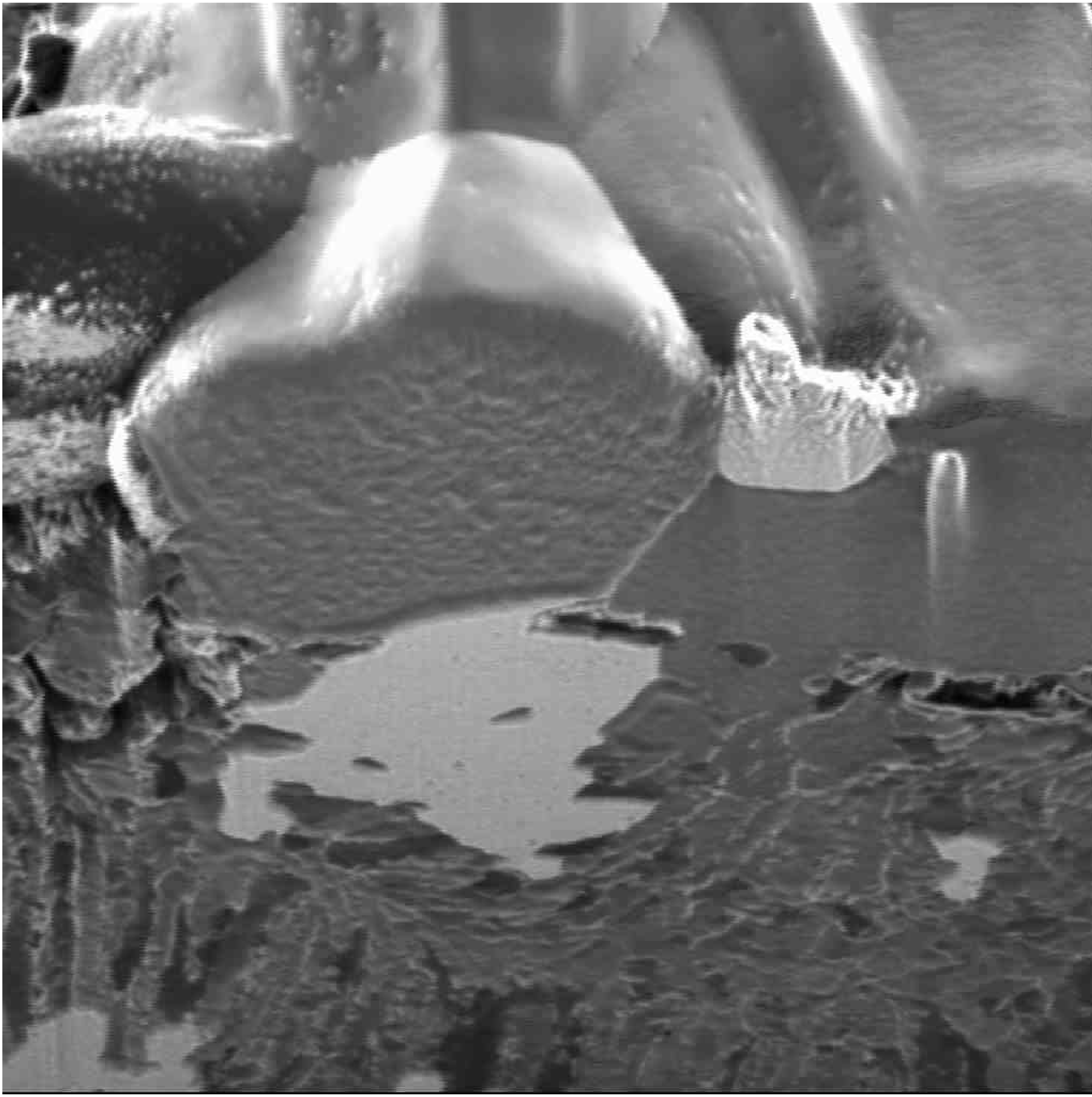
Note: not the same nodule in previous foil



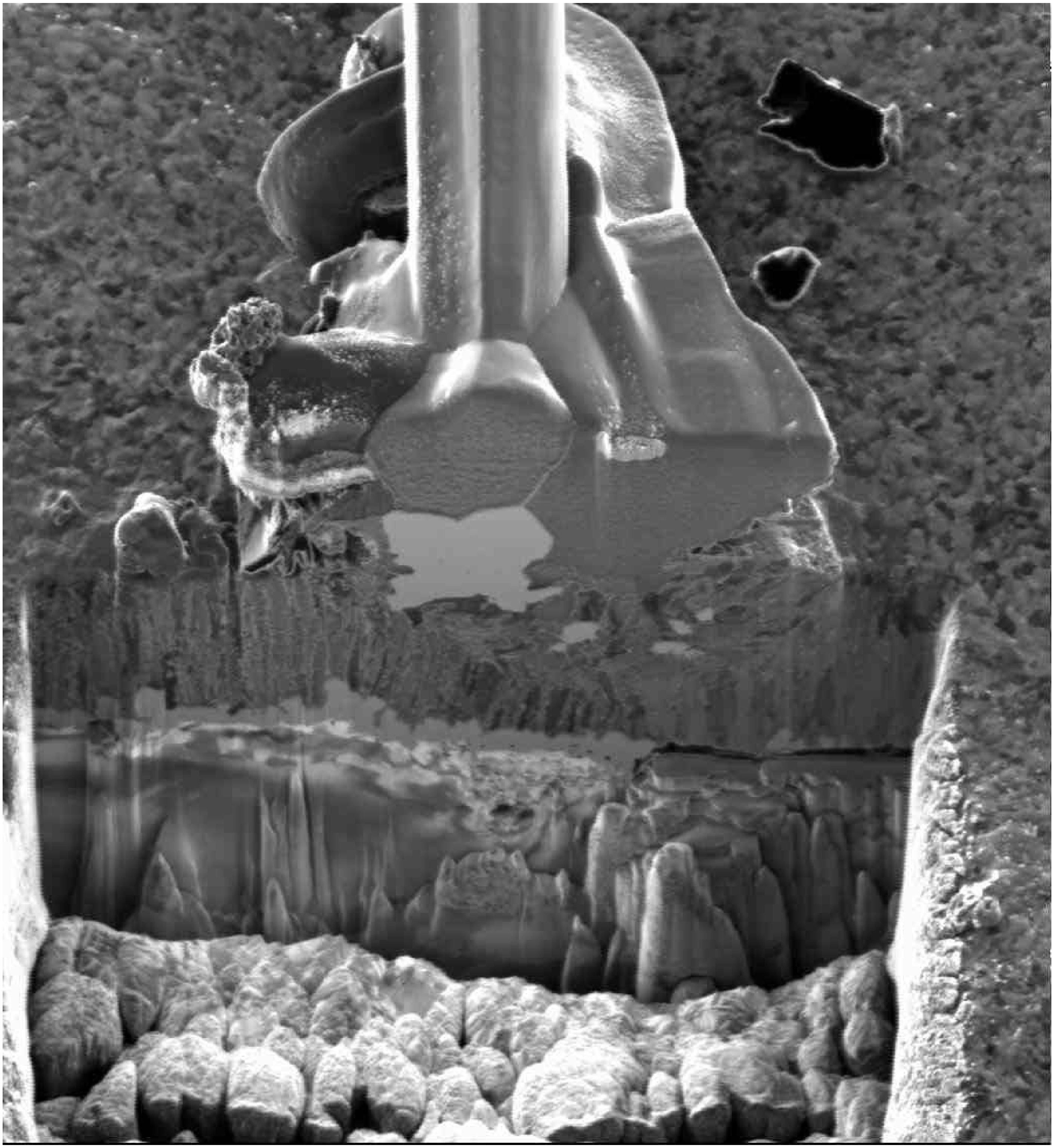
#5-1



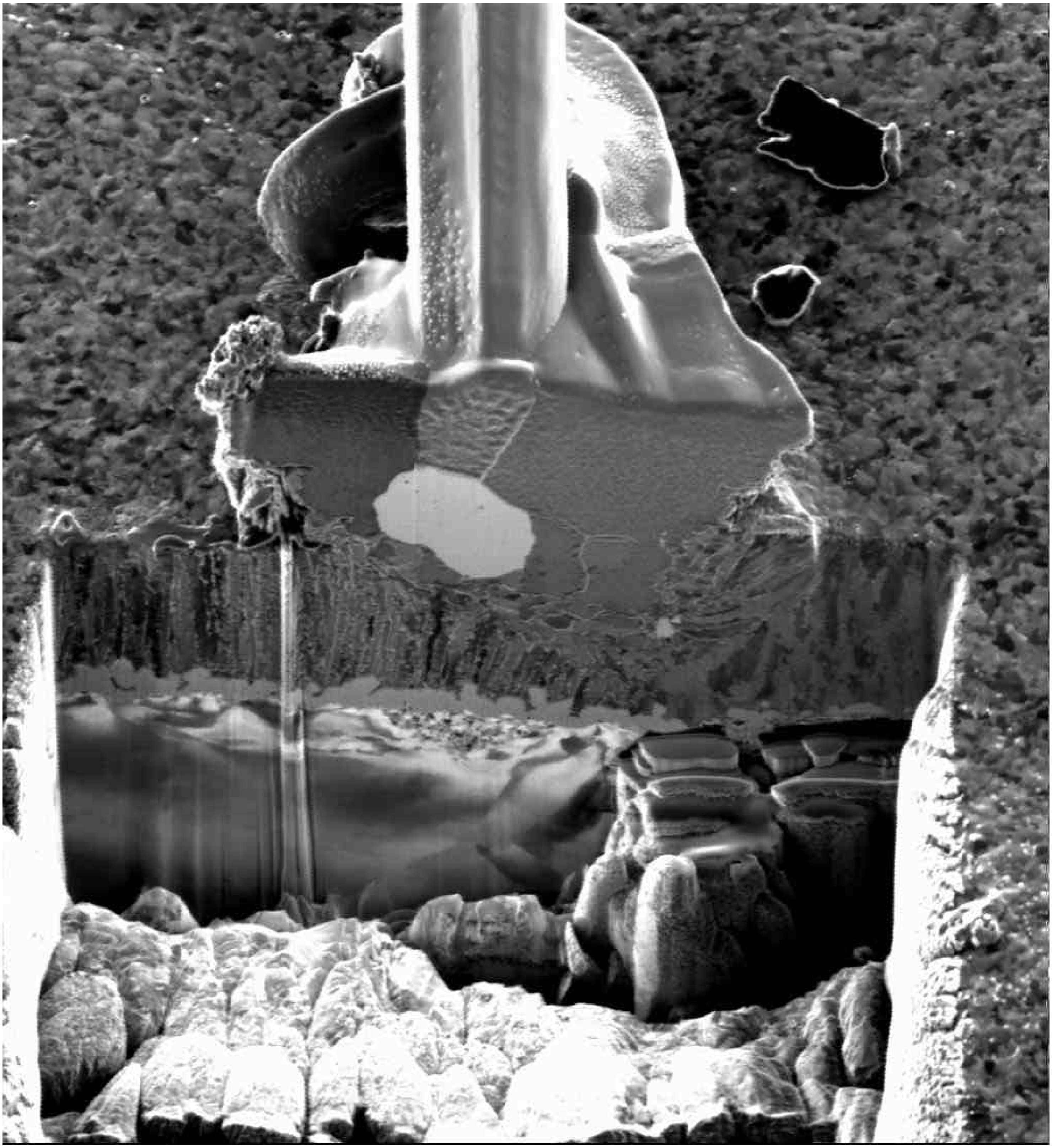
#5-3



05-5

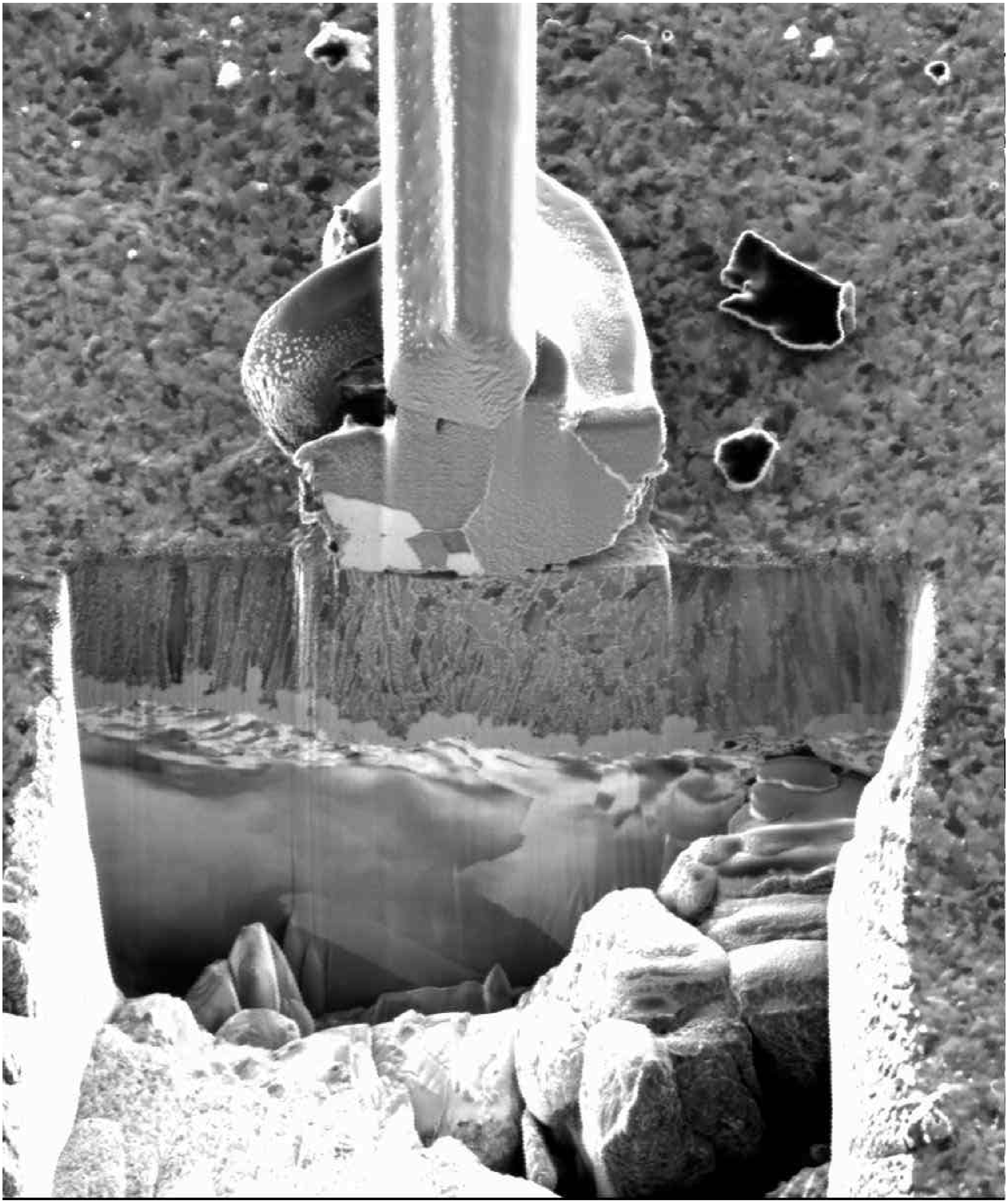


#5-6

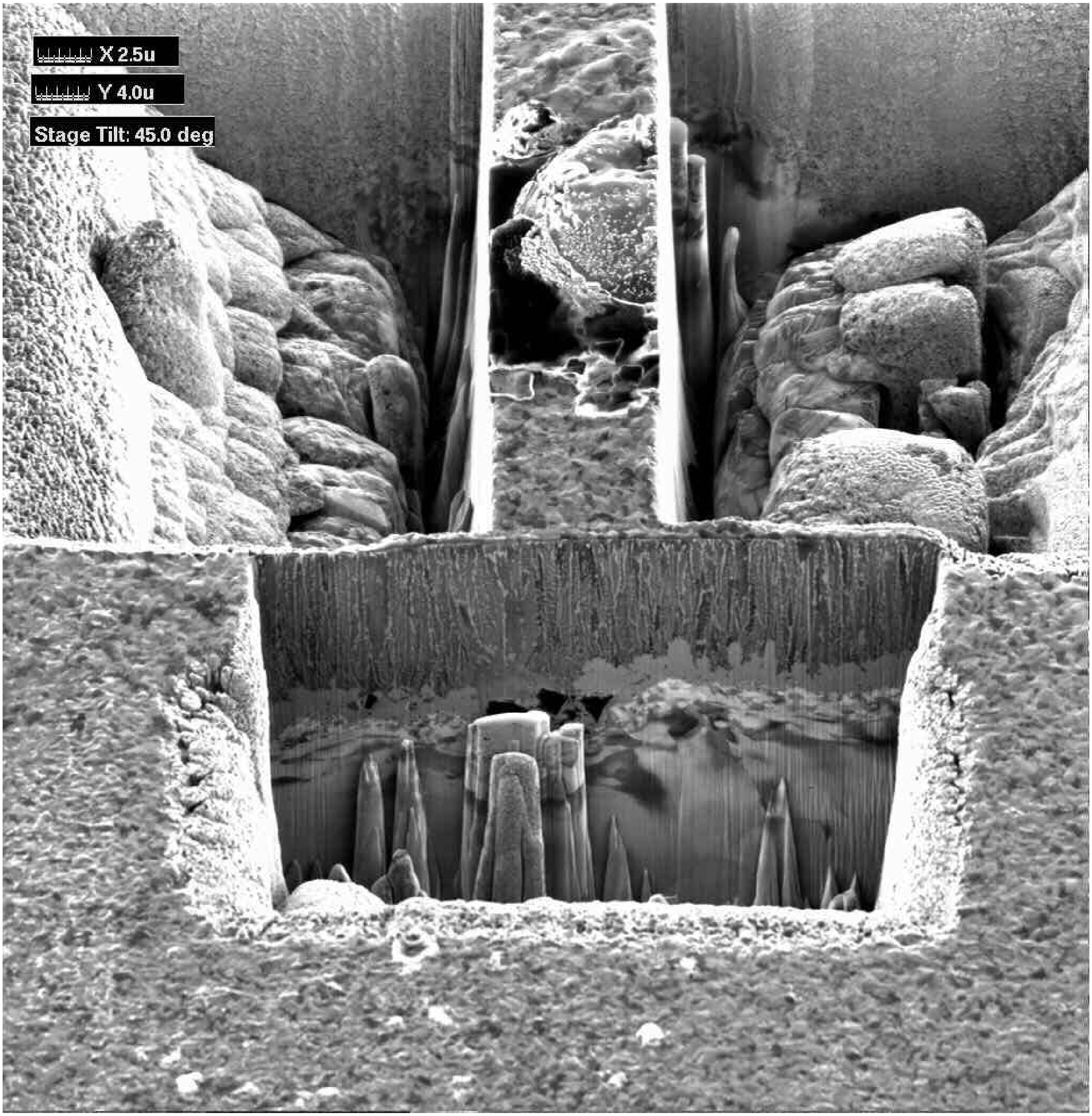


#5-8

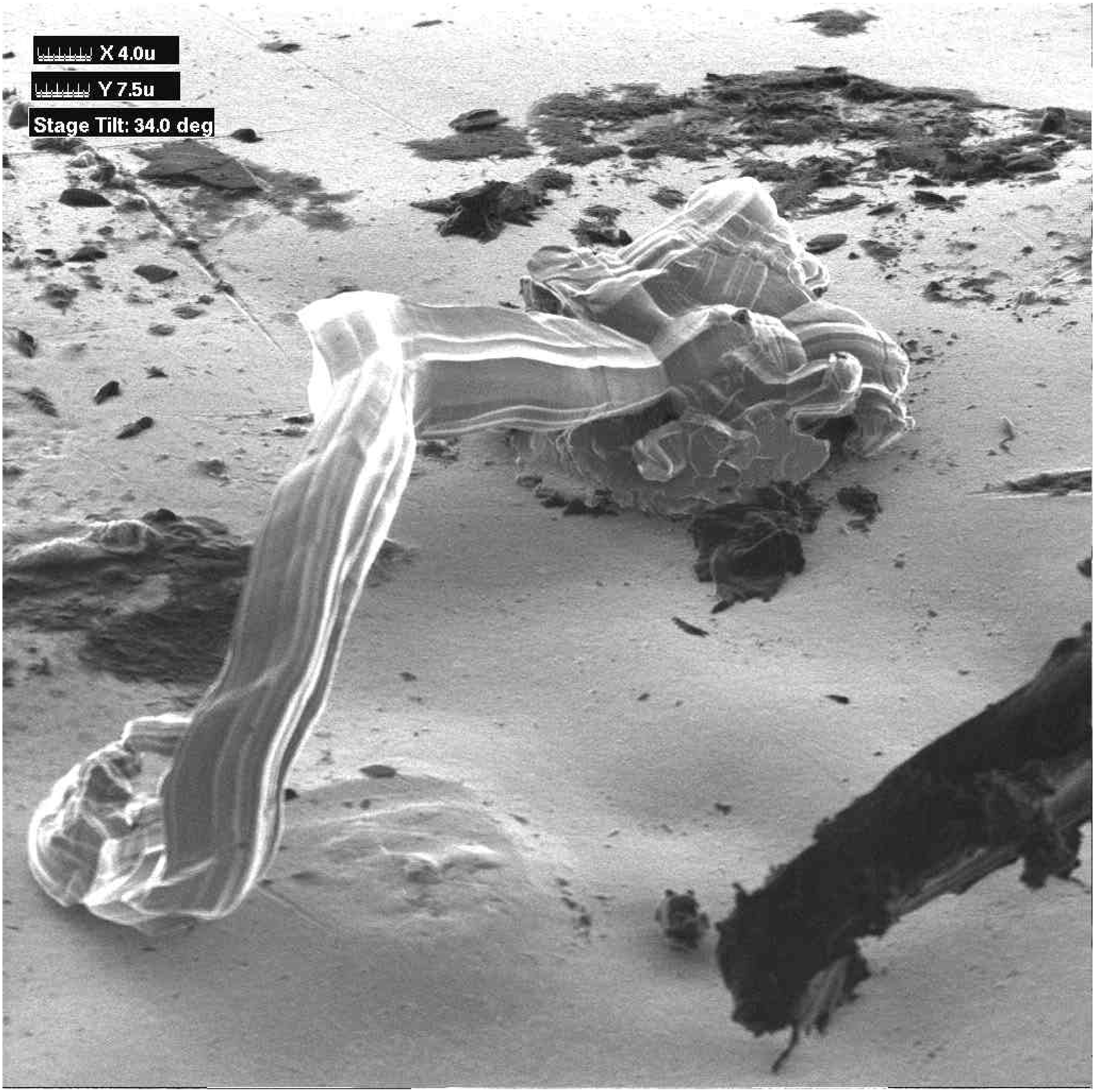
#5-11



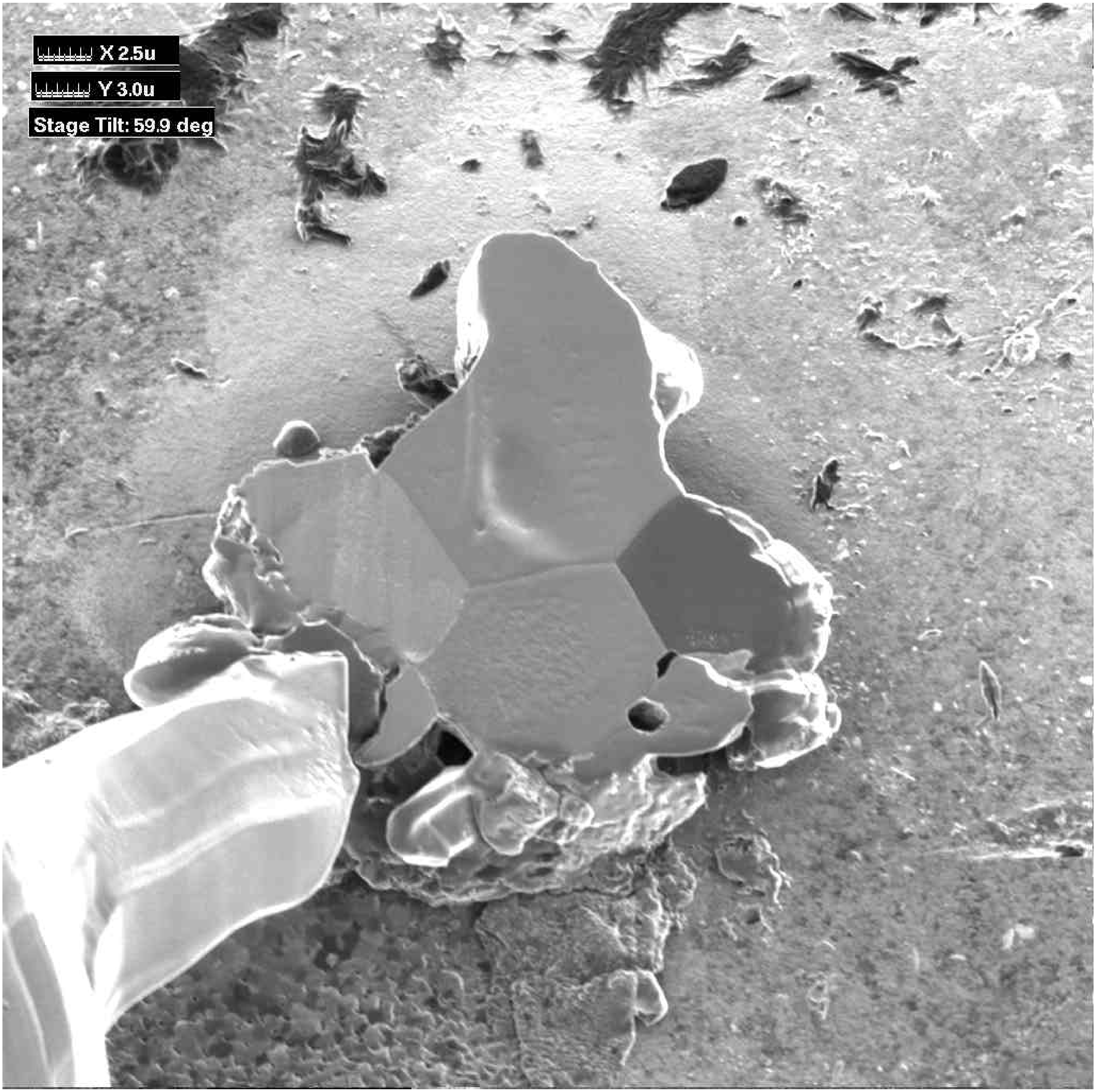
#5-14



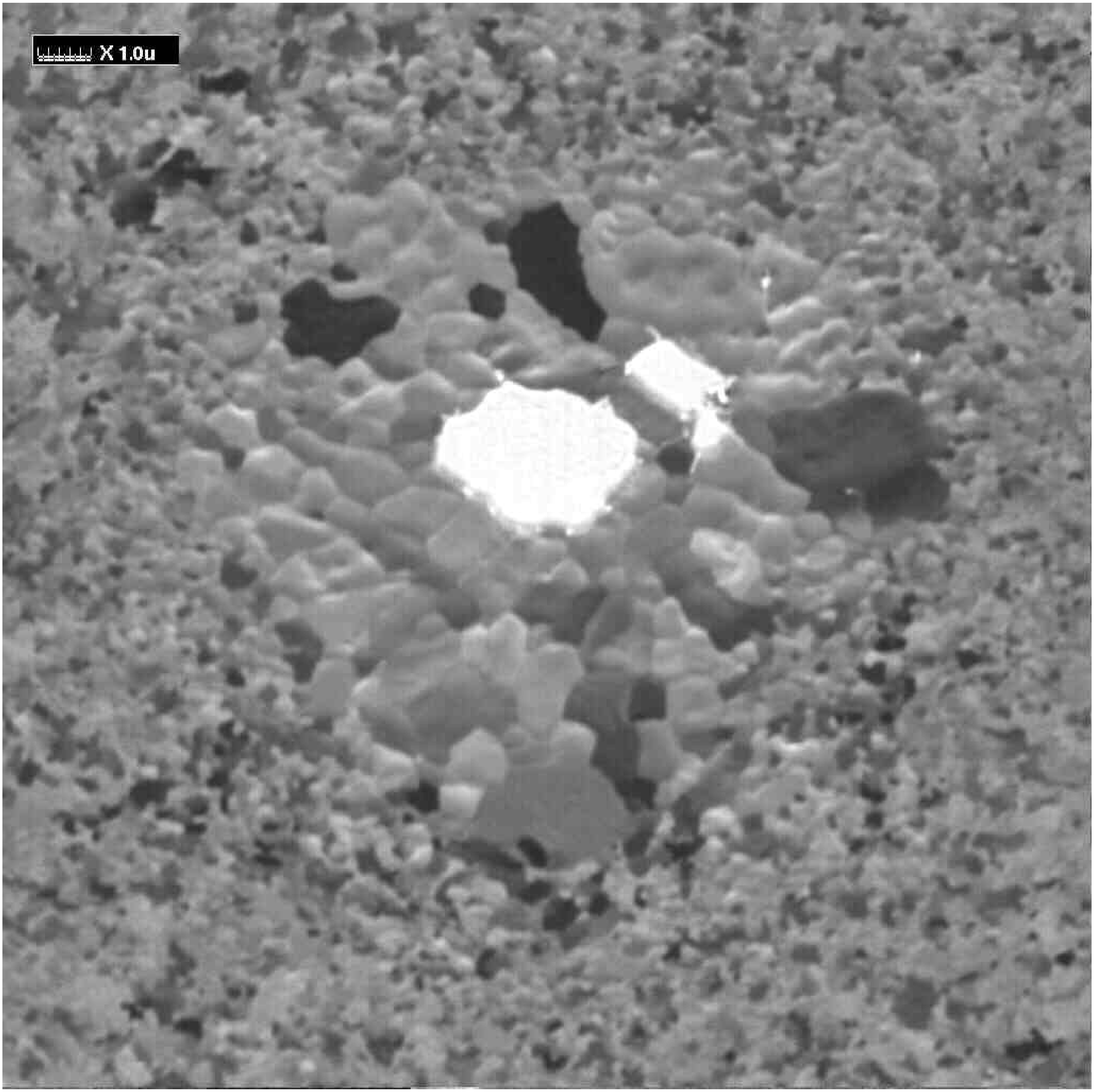
Triple Trench-bright tin nodule



Plan View HS5-01

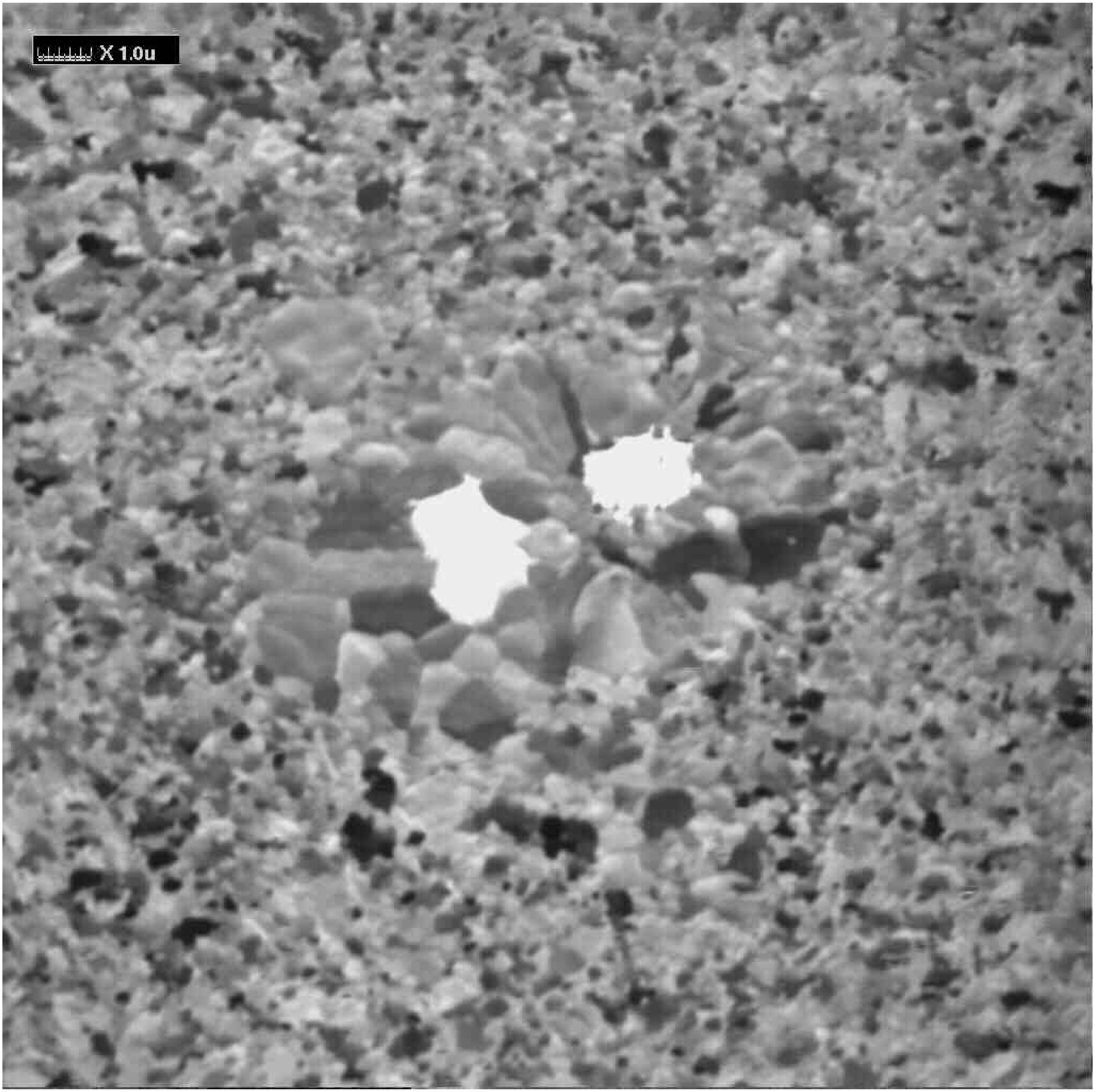


Plan View HS5-03

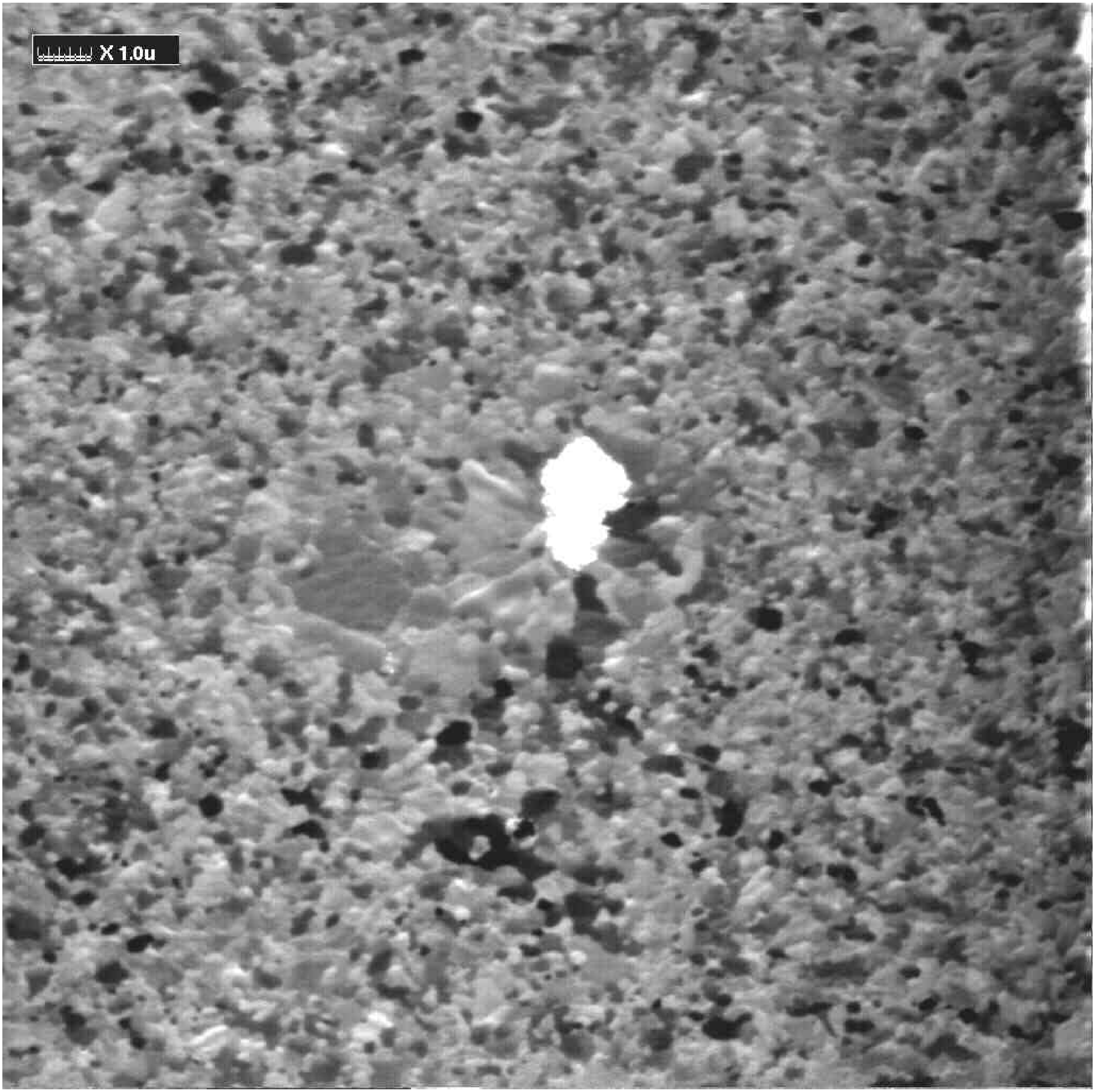


HS5-08

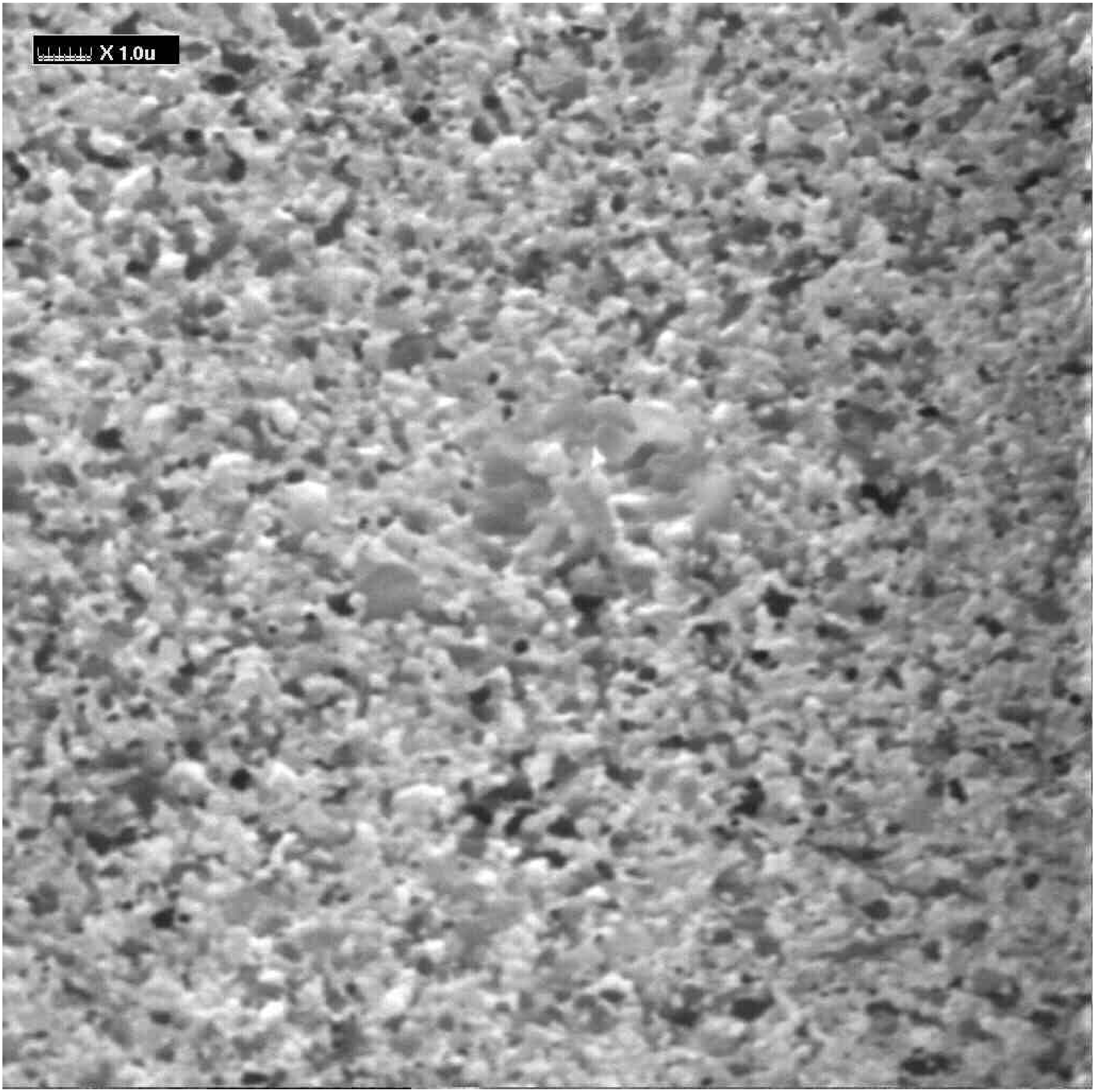
Plan View HS5-09



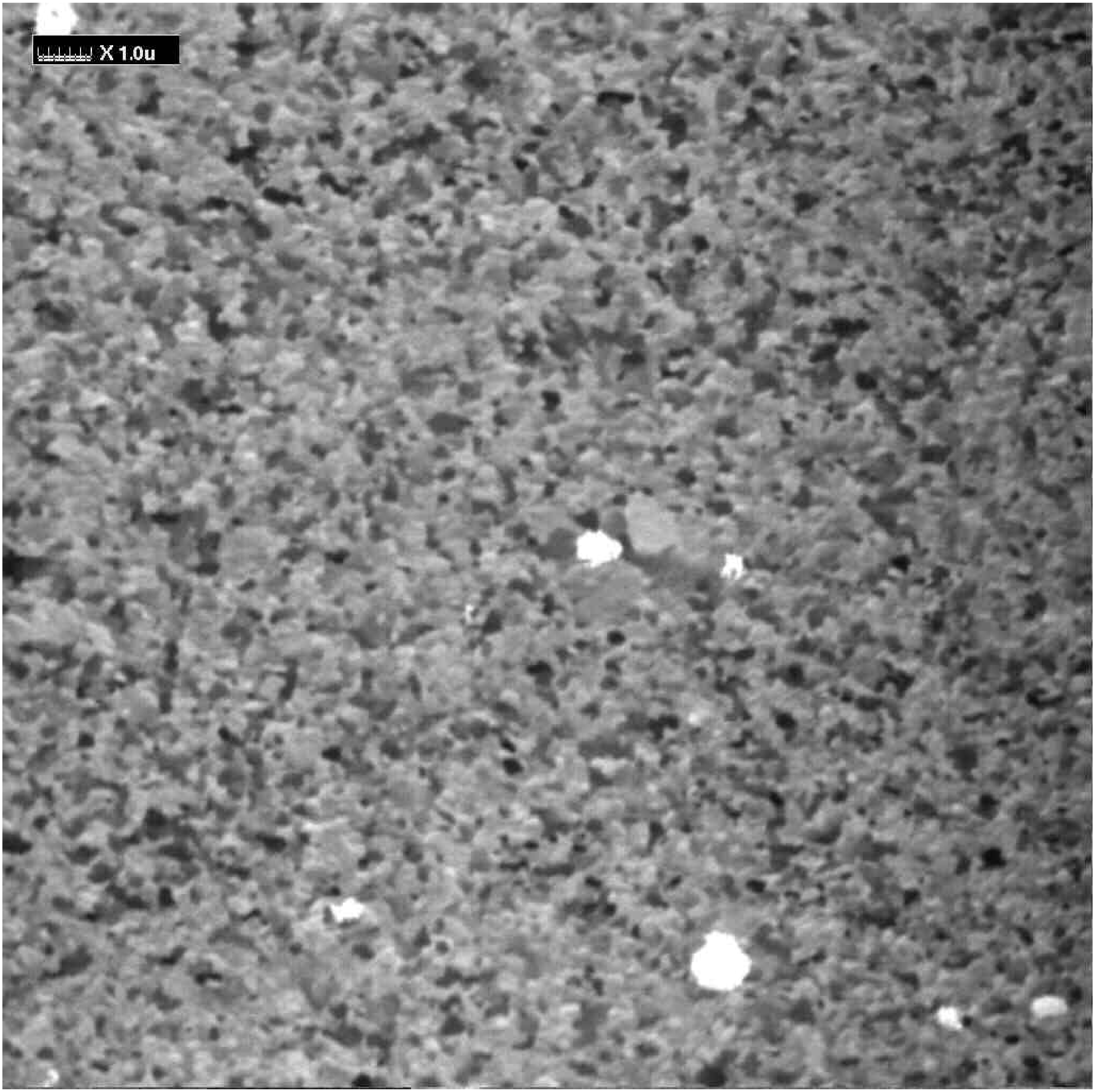
Plan View HS5-011



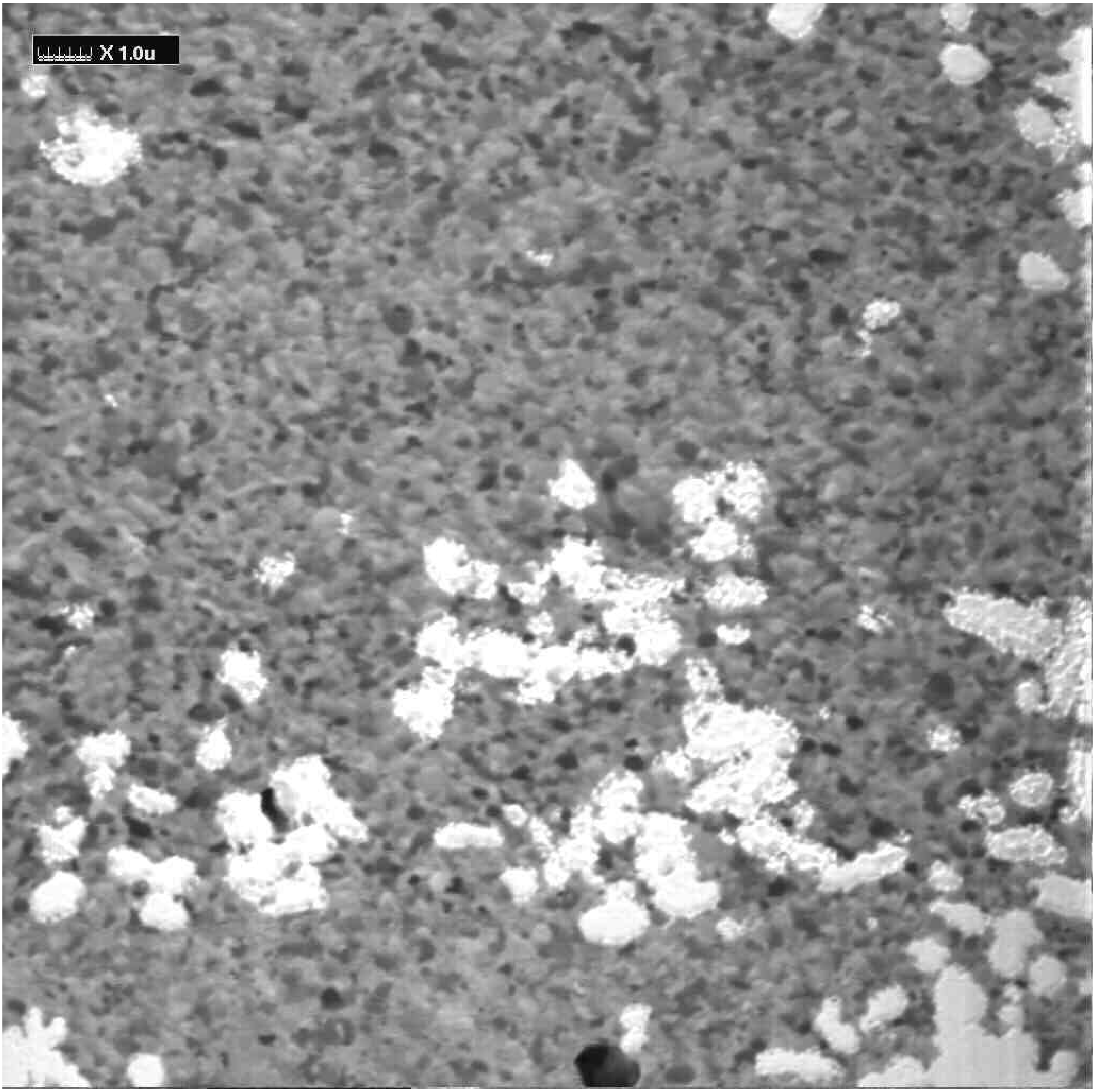
Plan View HS5-013



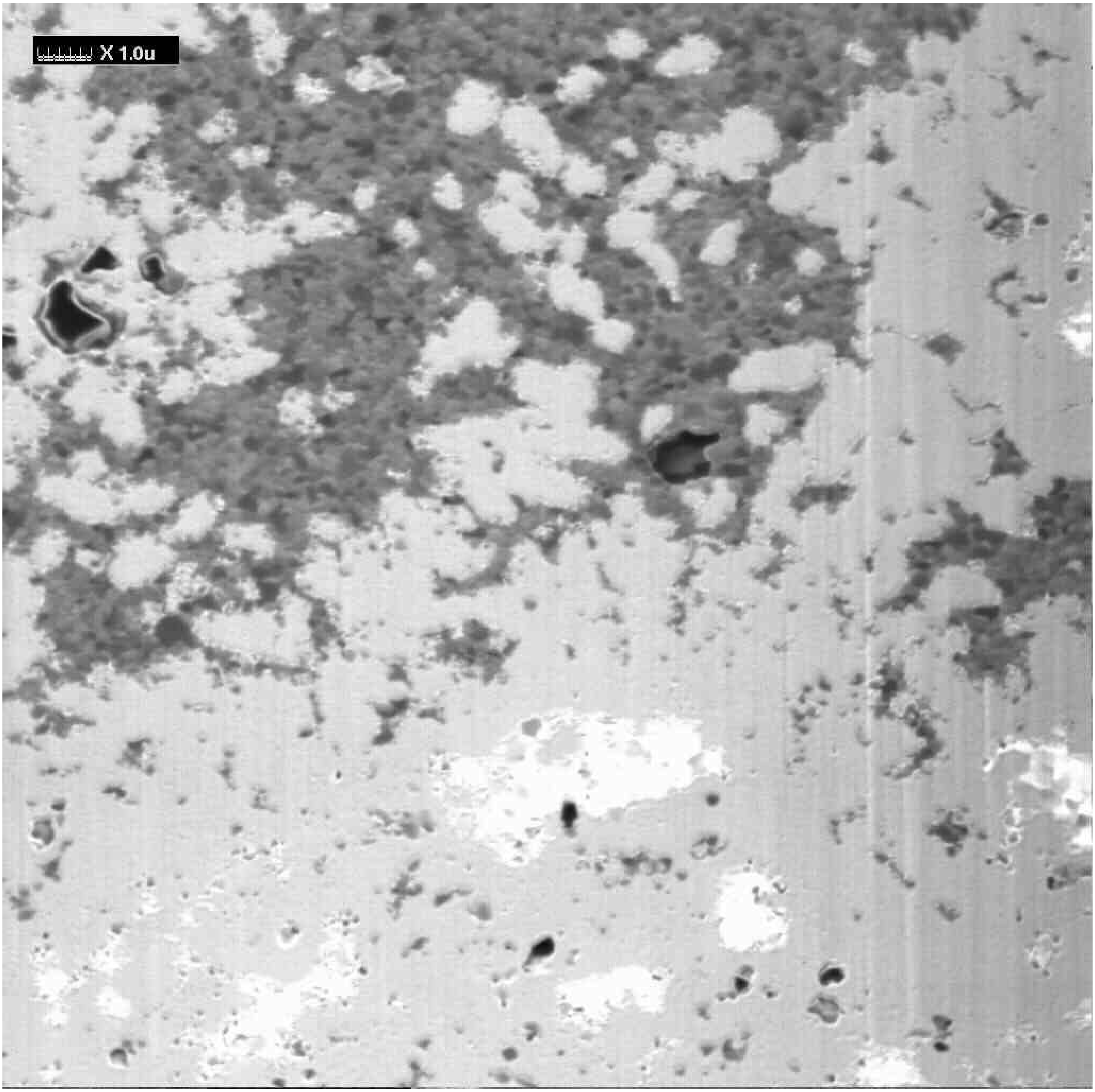
Plan View HS5-014



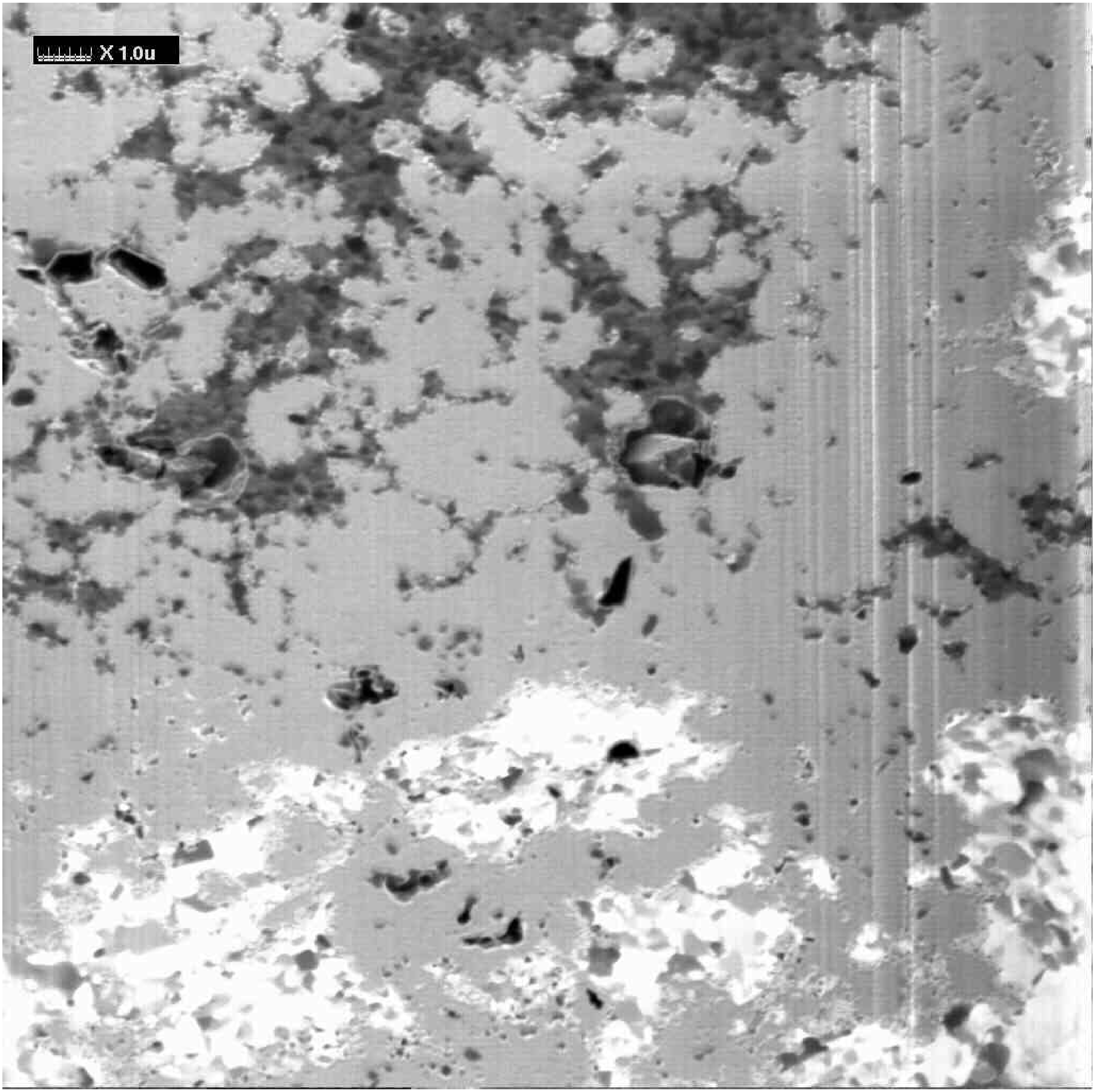
Plan View HS5-017



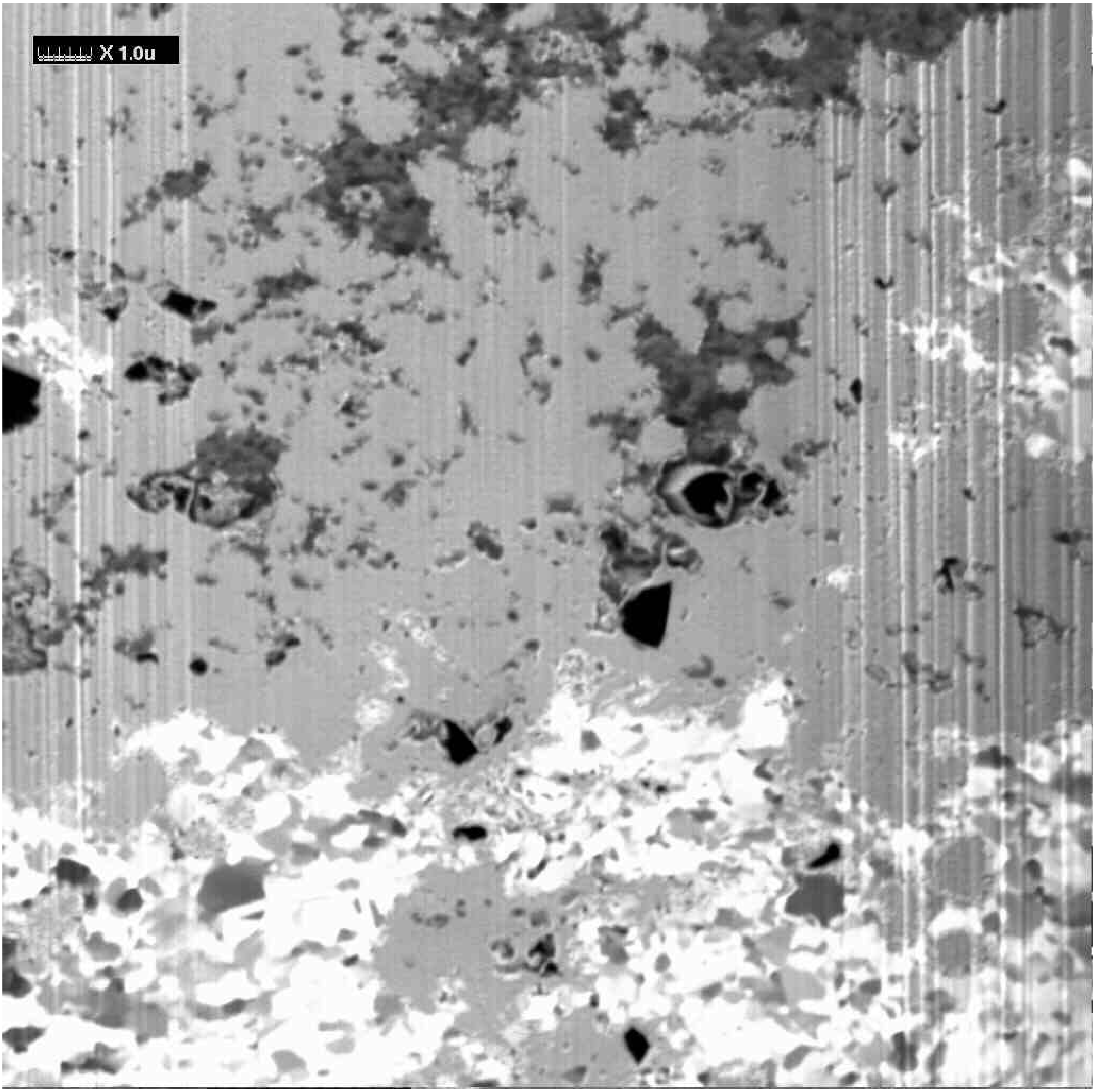
Plan View HS5-019



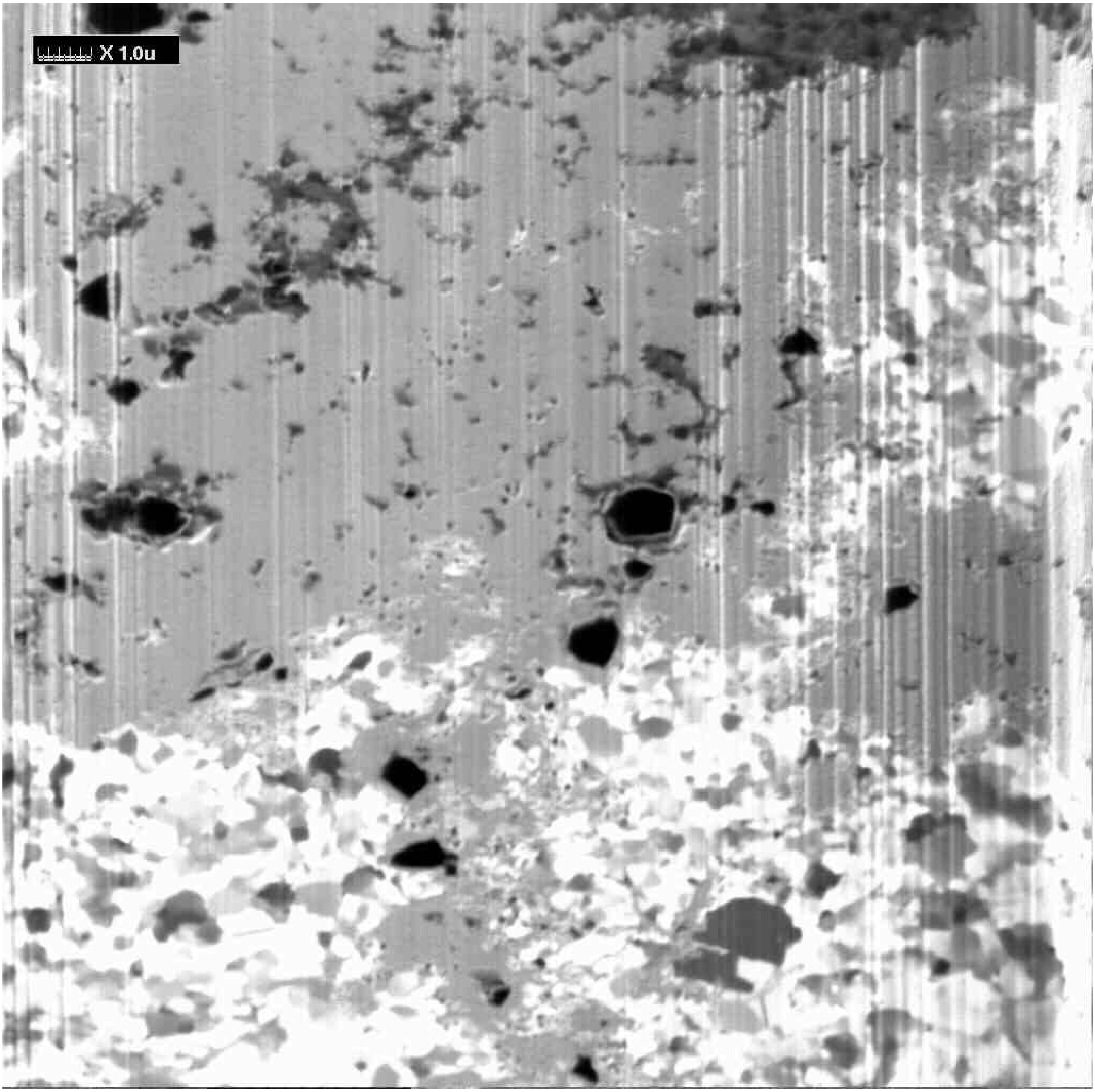
Plan View HS5-21



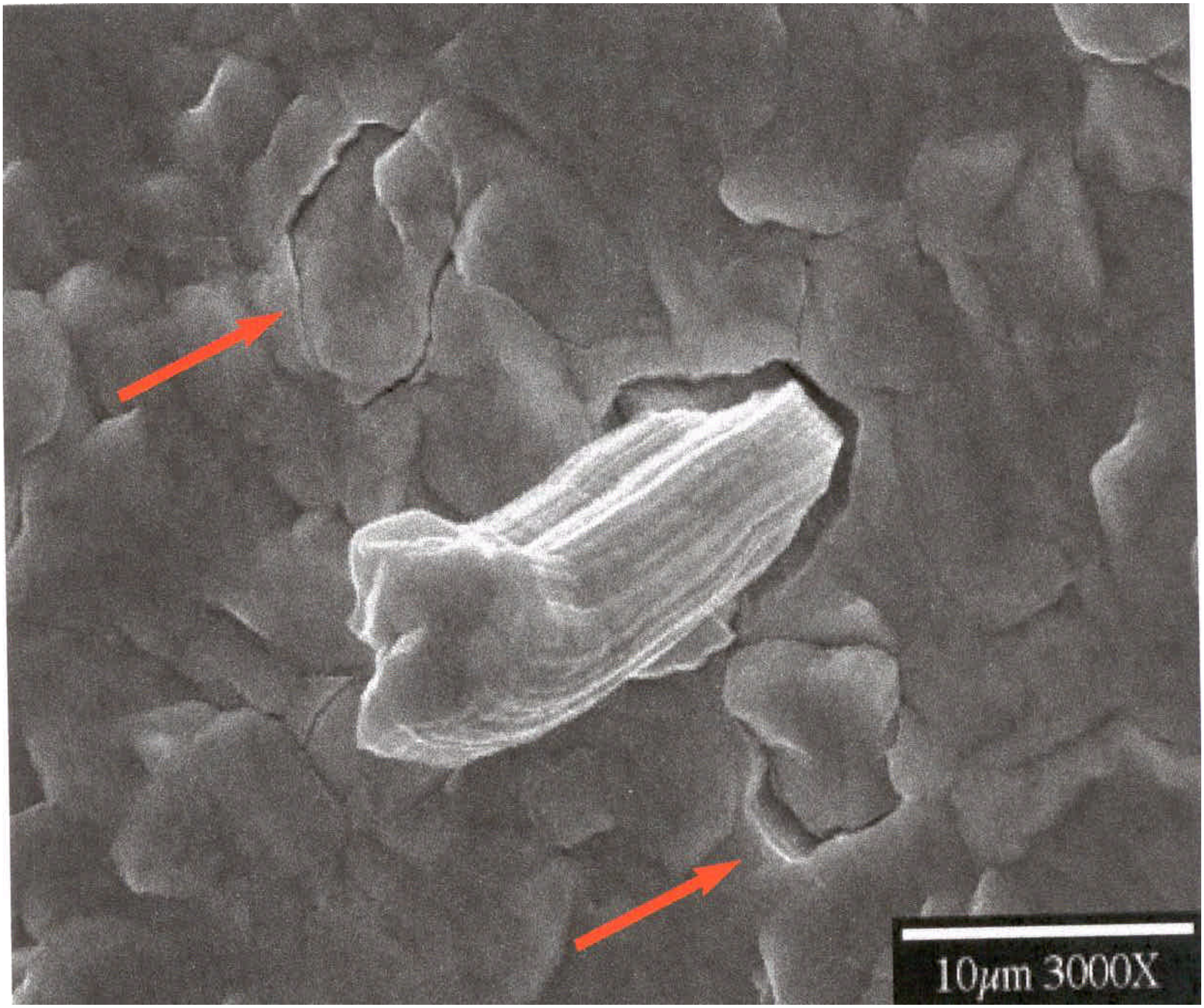
Plan View HS5-022



Plan View HS5-023

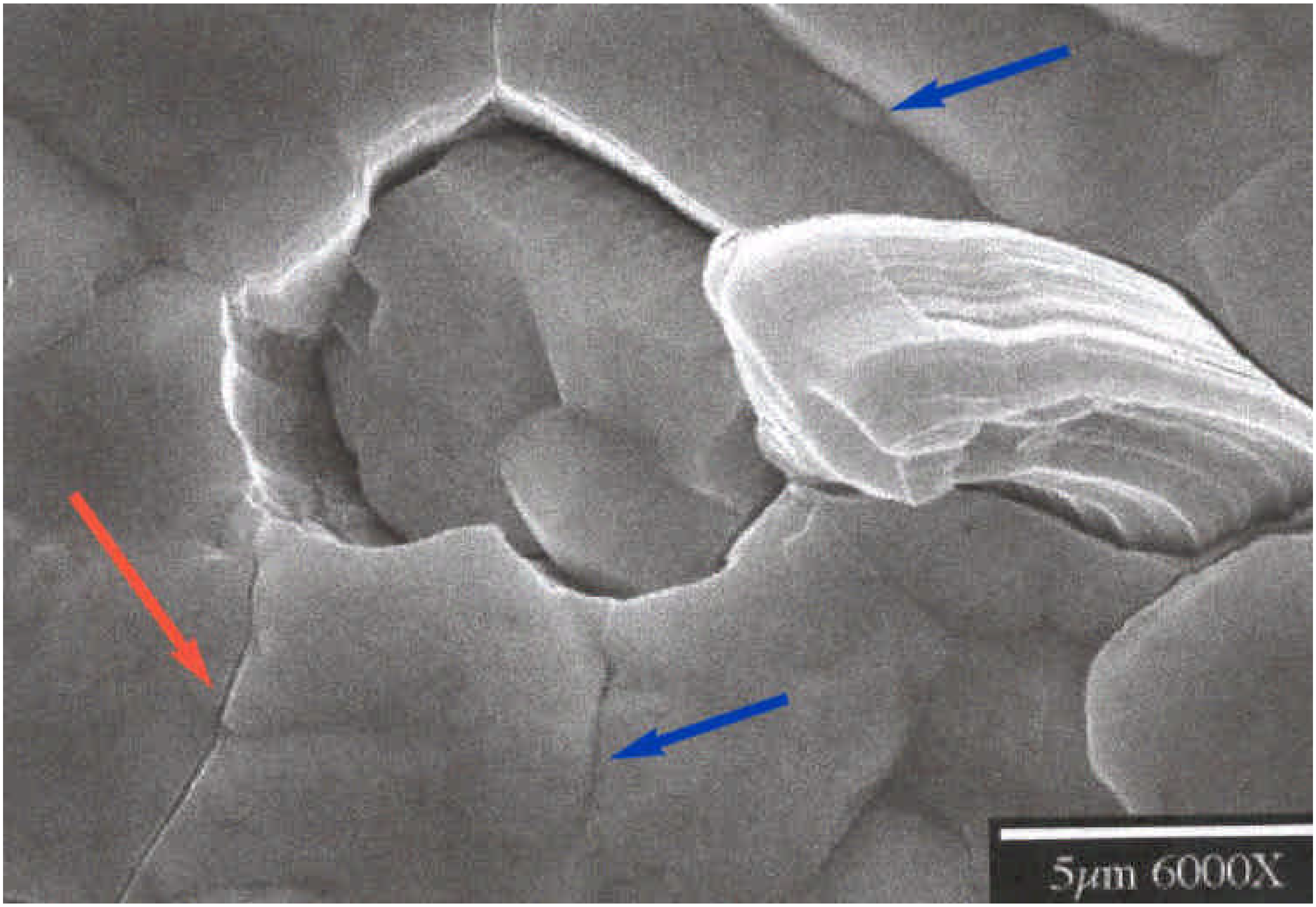


Plan View HS5-024



courtesy Peter Bush/Irina Boguslavsky

First examples of "remote grain subsidence"



courtesy Peter Bush/Irina Boguslavsky

Scratch-WK10
Bright Tin: FIB cross-section / FIB Micrograph
Whiskers only on scratch
Field Return-3+yrs. of service

Scratch-WK08

Bright Tin: FIB cross-section / FIB micrograph

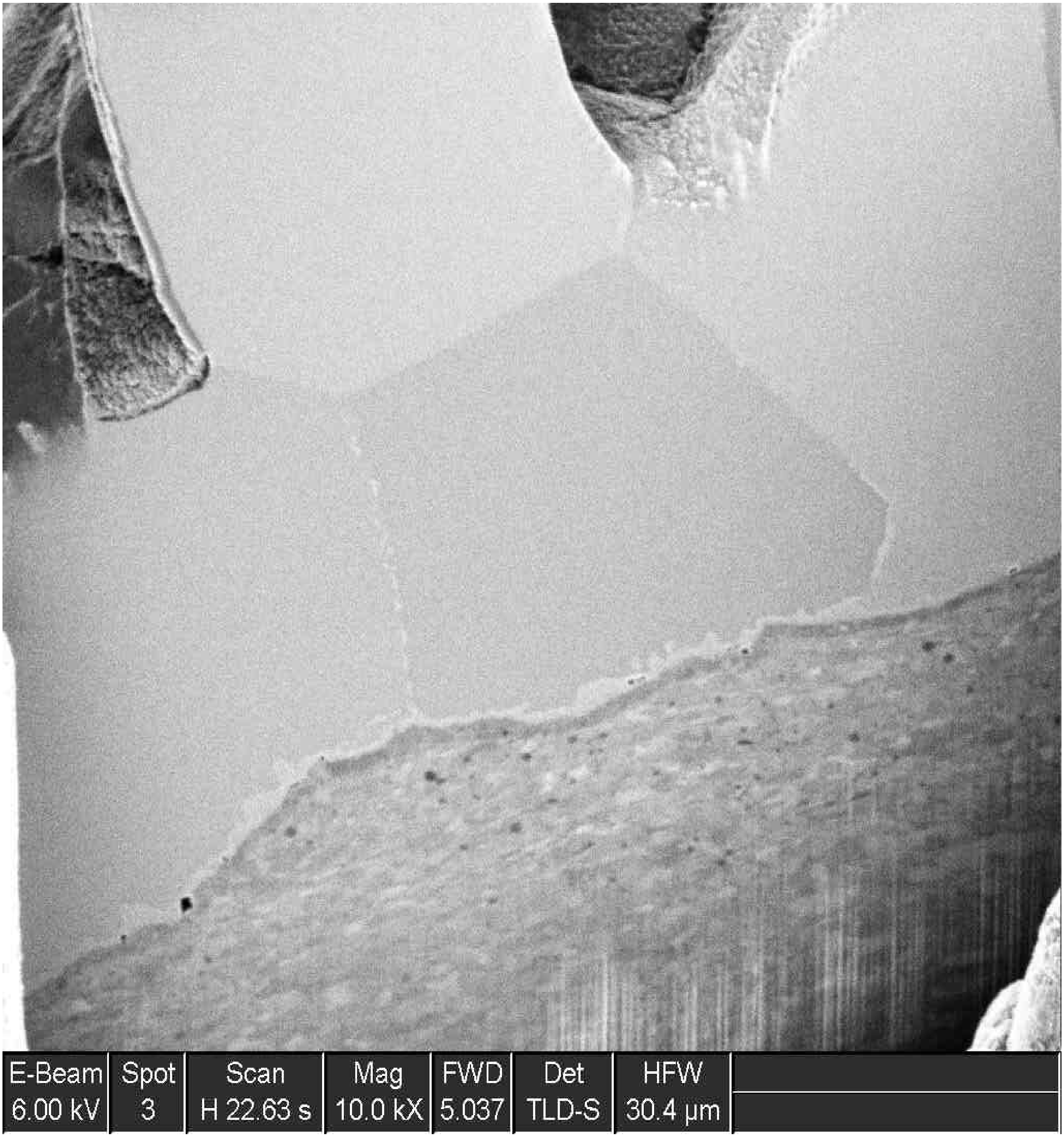
Scratch-WK06

Bright Tin: FIB cross-section / FIB micrograph

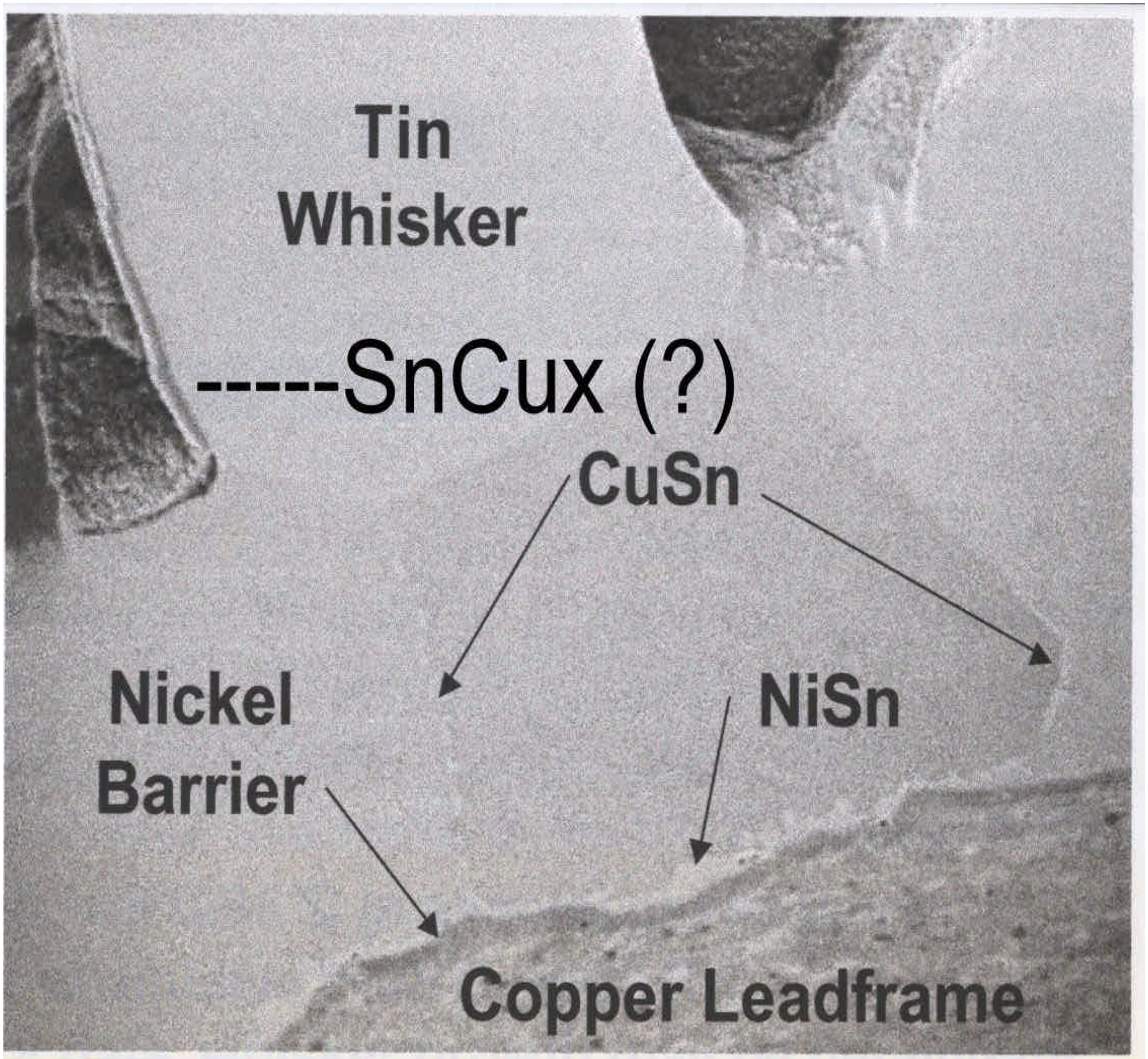
Scratch WK03
Bright Tin: FIB cross-section / FIB micrograph

Scratch WK-01

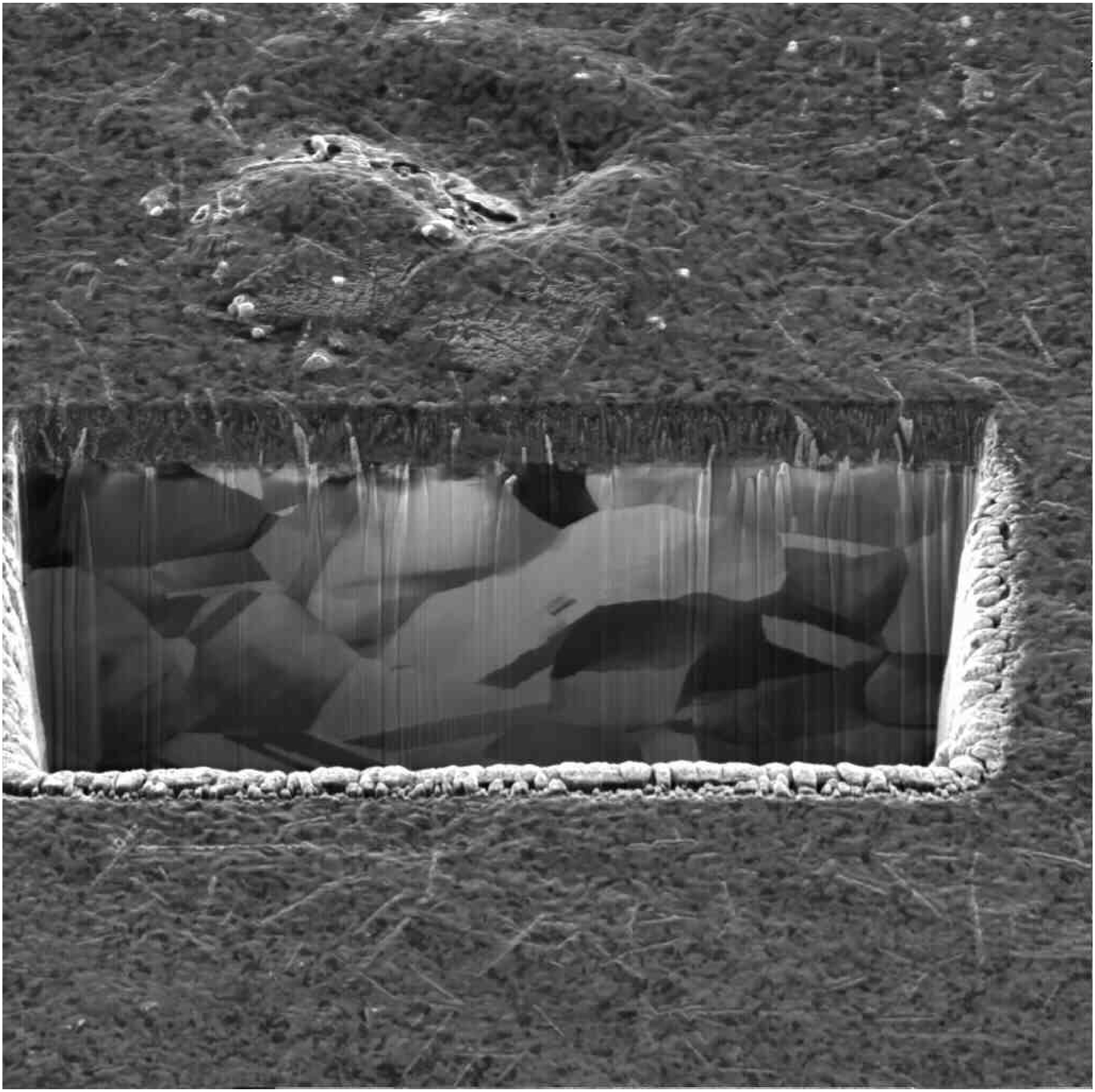
Bright Tin: FIB cross-section / FIB micrograph



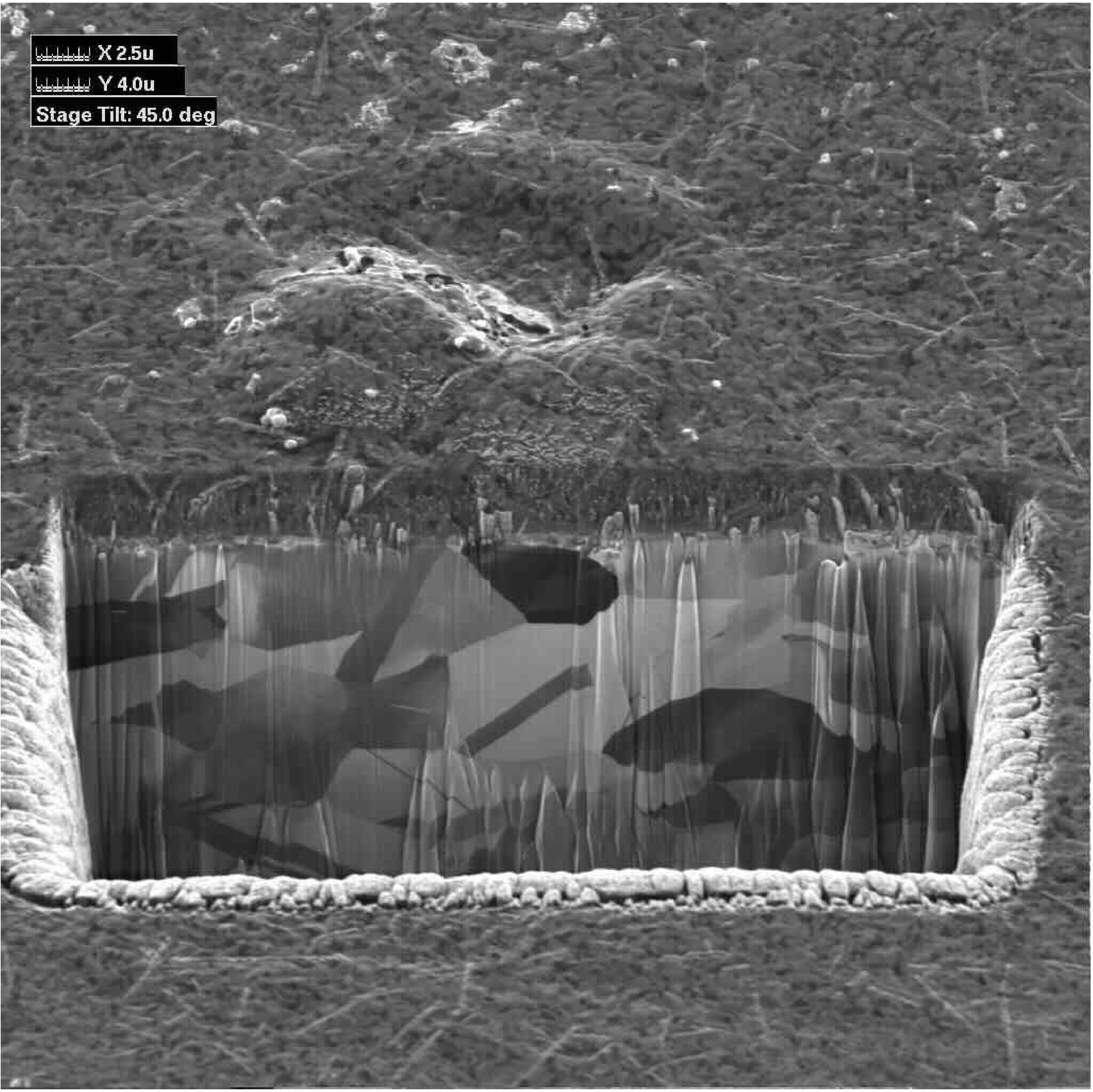
courtesy: N. Vo, Motorola Corp.
Matte Tin (10u) over Ni (.5-1u)



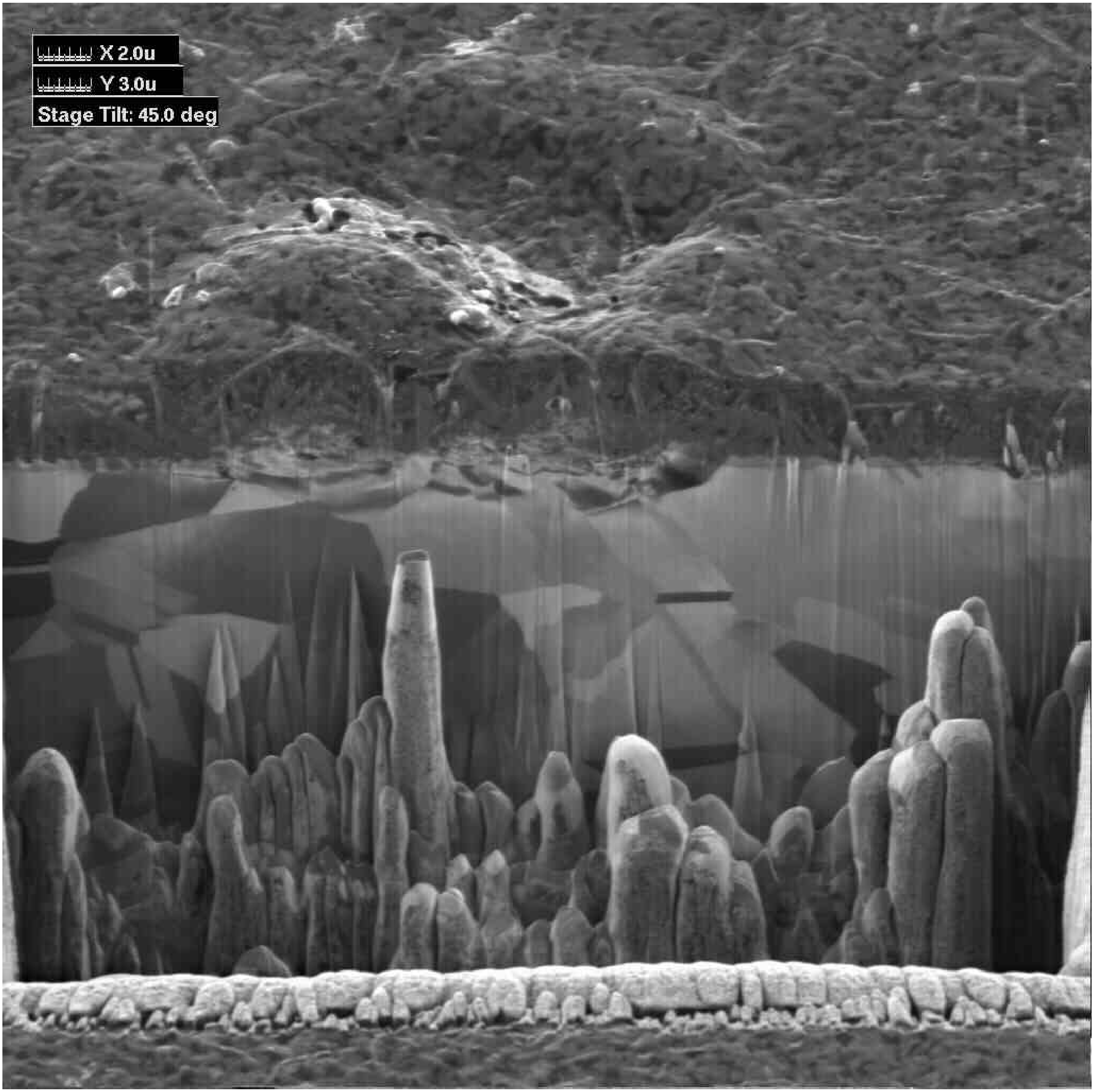
courtesy N. Vo-Motorola Corp.



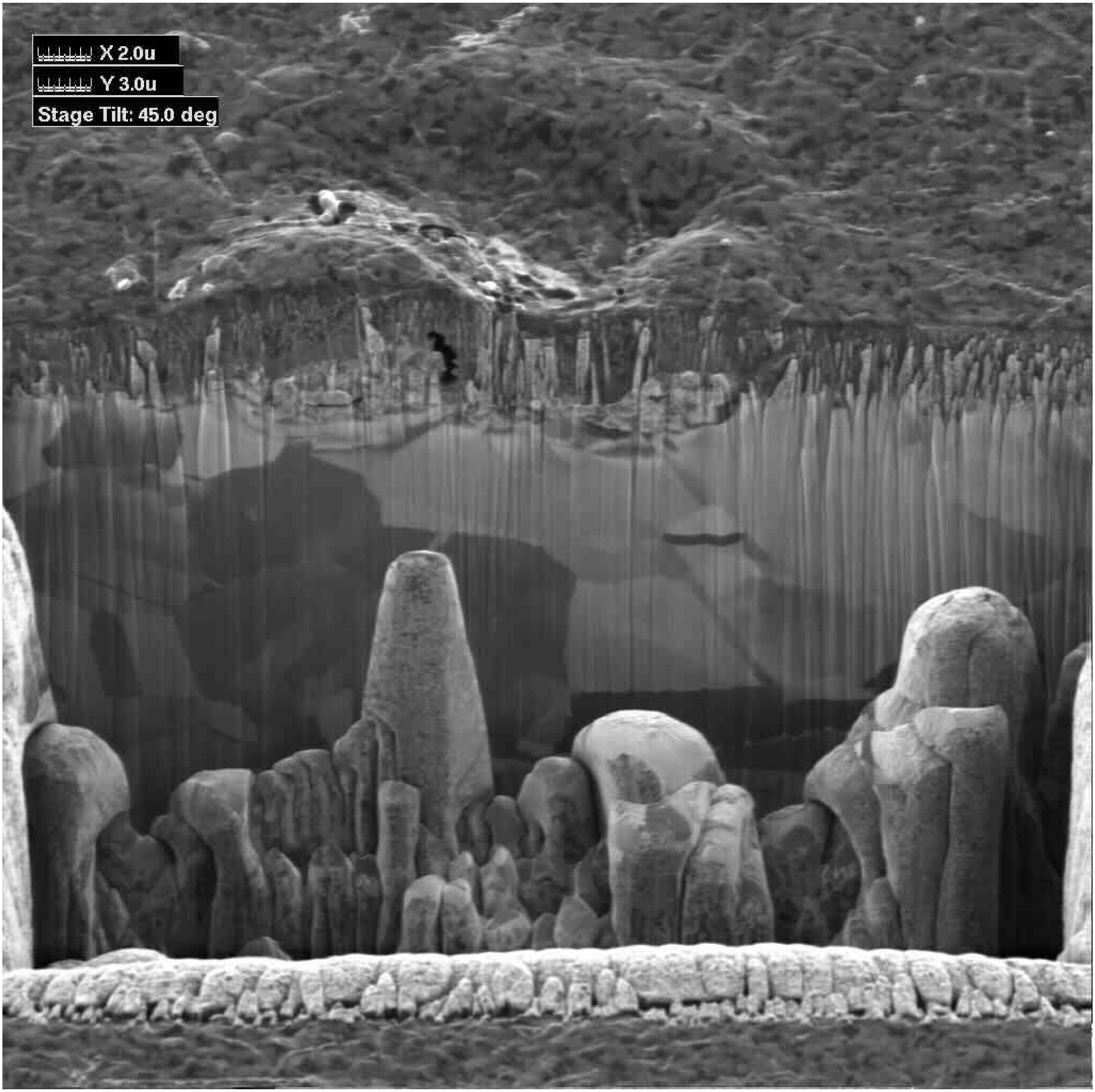
CuNiSn01
Bright Tin over Ni over Cu
Field Service-no whiskers observed



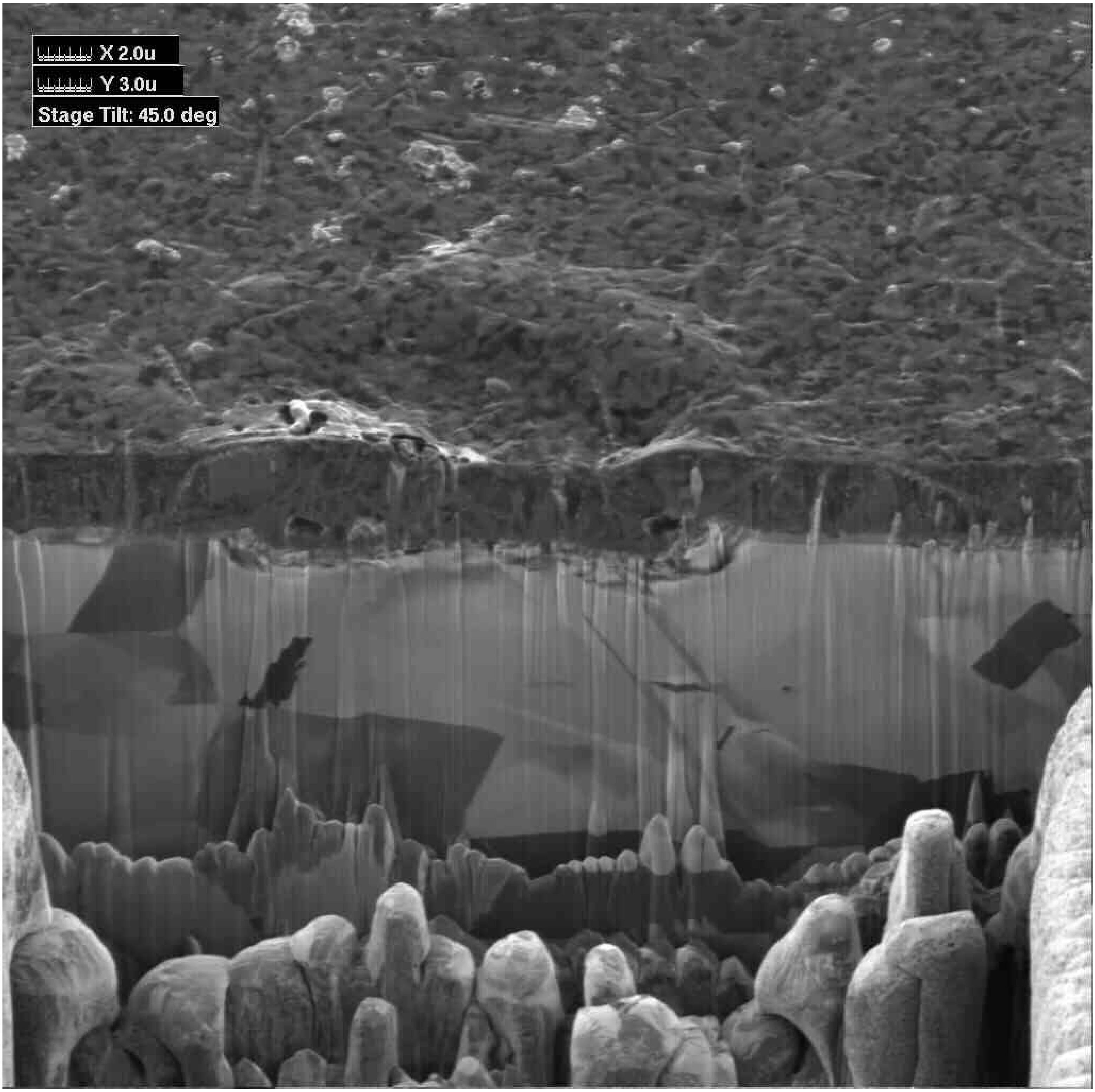
CuNiSn05



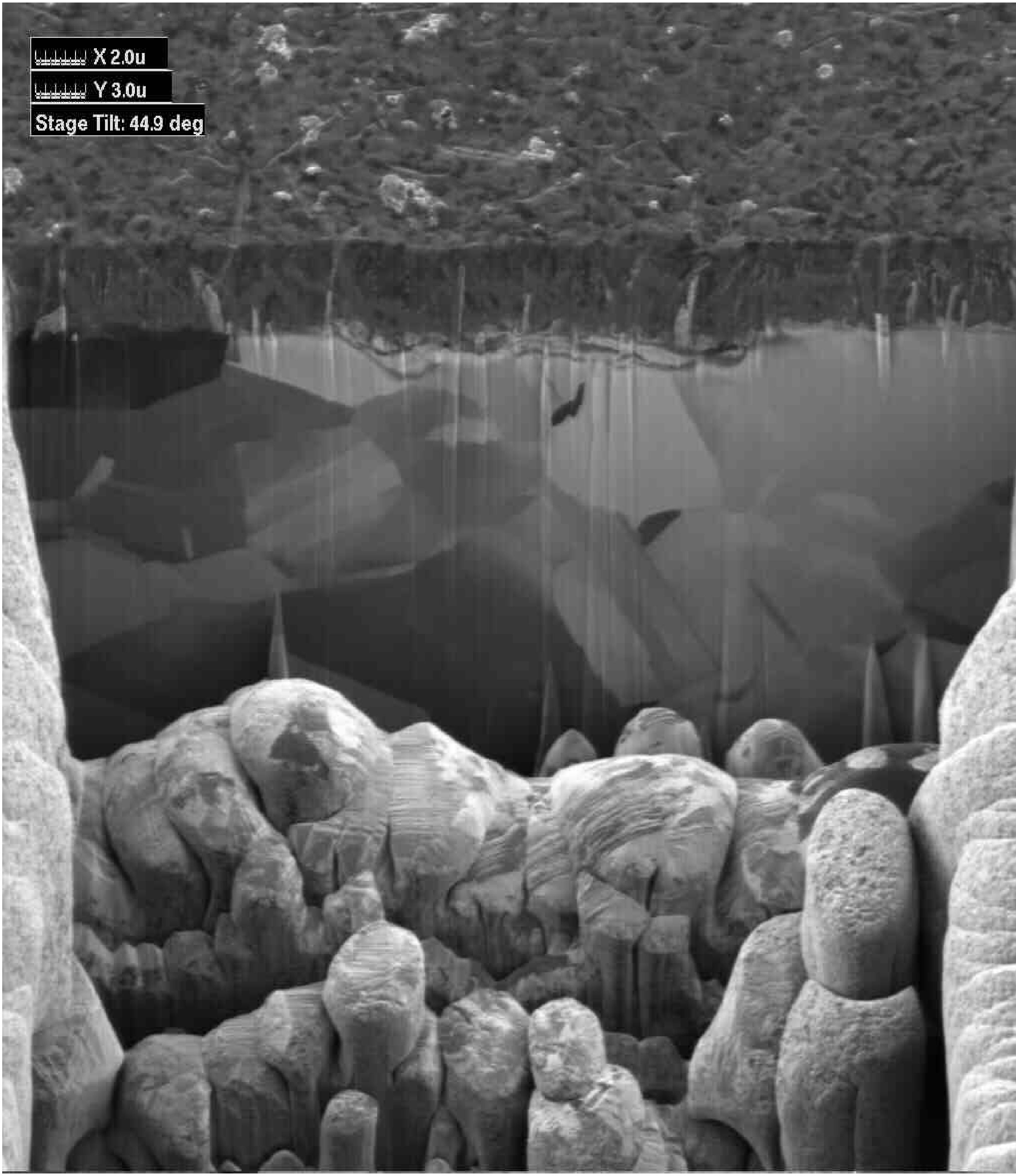
CuNiSn08



CuNiSn10



CuNiSn12



CuNiSn18

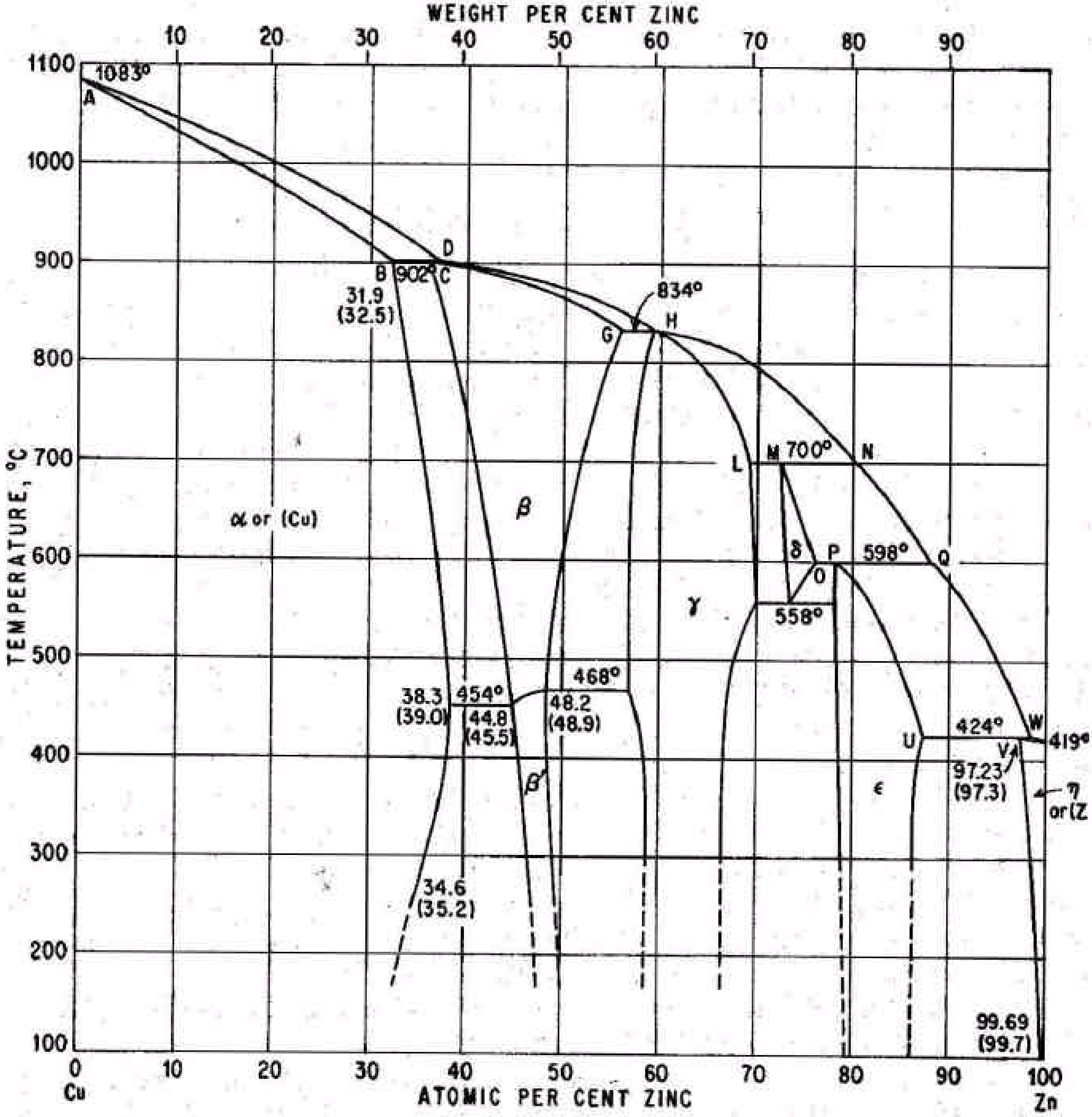

WEIGHT PER CENT ZINC
10
20
30
40
50
60
70
80
90
1100
1000
900
800
700
600
500
400
300
200
100
TEMPERATURE, °C
1083°
A
D
B
902°
C
31.9
(32.5)
834°
G
H
L
M
700°
N
α or (Cu)
β
δ
P
598°
Q
O
558°
γ
468°
38.3
(39.0)
454°
44.8
(45.5)
48.2
(48.9)
424°
W
419°
U
V
97.23
(97.3)
β'
ε
η
or (Z
34.6
(35.2)
99.69
(99.7)
0
Cu
100
Zn
ATOMIC PER CENT ZINC

Fig. 367. Cu-Zn

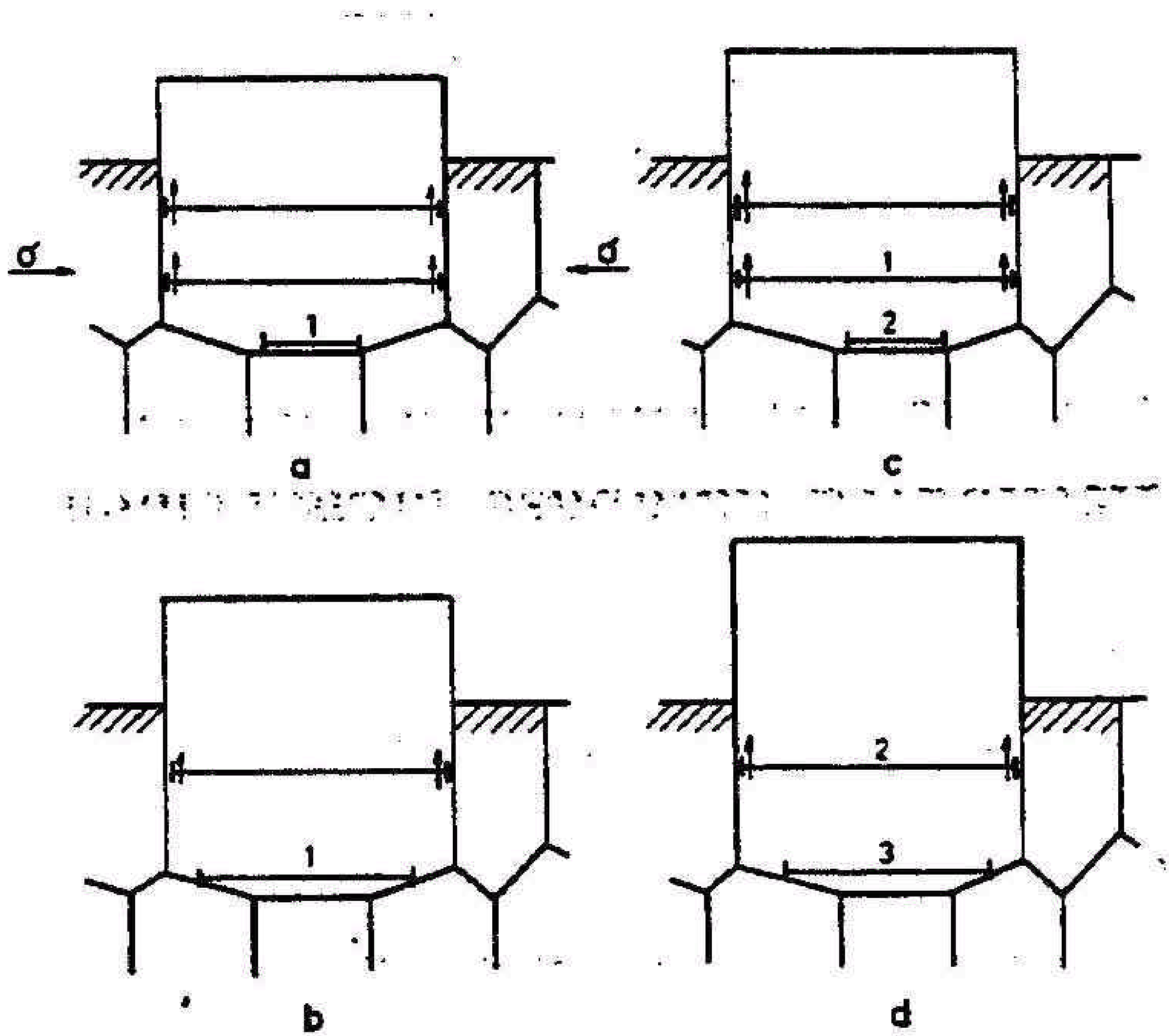


Fig. 2. Whisker growth model. (a, b) An extra plane of atoms expands by climb of the surrounding edge dislocation loop marked 1. (c) Loop no. 1 has reached full size and started to glide upwards. A second loop has started to expand. (d) Loop no. 1 has reached the surface and pushed out the whisker one atomic spacing. The subsequent loop is in the gliding stages and a third loop is expanding by climb.

ref. U. Lindborg-Acta Met., 1976