Stardust Foil C2125N,1 “Walton”

Survey of entire top surface of the foil to identify, locate, measure and count all hypervelocity impact features of 5 microns and larger.

Three impact features found: 1) 9.3 x 8.8 microns; 2) 2.4 microns and 3) 5.7 x 3.9 microns.

Detailed survey of 5.75 mm^2 to locate and measure all craters > 600nm diameter. None found.

Secondary electron and backscattered electron imagery. Stereometric anaglyph and depth profile of complex impact feature. Energy Dispersive X-ray mapping and analyses of residues.

Techniques employed

C2125N,1

Foil mounting onto high purity Al sheet using high purity Sn wire restraints - the NHM ‘Gulliver technique’ (performed at OU).

Low resolution location map of entire foil in secondary electron mode, and creation of 2 fiducial marks in areas with no impact features, at opposite ends of the foil, using a focussed ion beam (performed at OU).

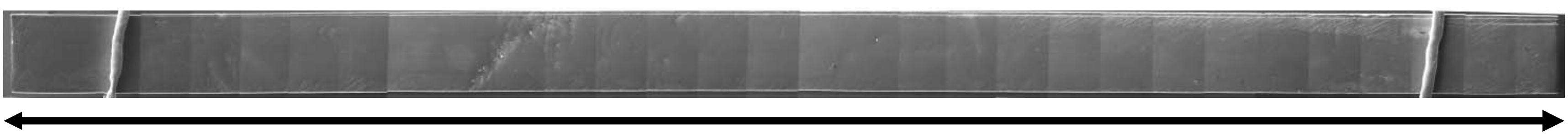
Automated backscattered electron montage creation in flat, central area of foil at high magnification (x1000 magnification, 126 micron lateral field of view, 1024 pixels, c. 12 hrs). 1500 images created, covering 12.4 square mm, each frame examined visually (image acquisition at NHM, followed by examination at NHM, OU and Kent).

Manual survey of overlapping secondary electron images at x300 magnification, sample height correction applied, recognised features imaged and analysed to confirm impact origin (at NHM).

The ‘Gulliver’ method, using 250 μm thick 99.9999% Sn restraining wires, supported on a 99.99% Al sheet, for initial examination.

Test sample with two Sn wires.

Walton loaded on SEM stage



33.03 mm length (1.67 mm height)

Entire Stardust Foil C2125N,1 imaged at OU at low magnification, note tin wires.

High resolution BSE survey results.

C2125N,1

No unambiguous impact features of 5 microns or greater diameter were found in the 1500 frames comprising 12.4 square mm of BSE automated montages, acquired in four campaigns (c. 12 hours run) on the central (flat) part of the foil.

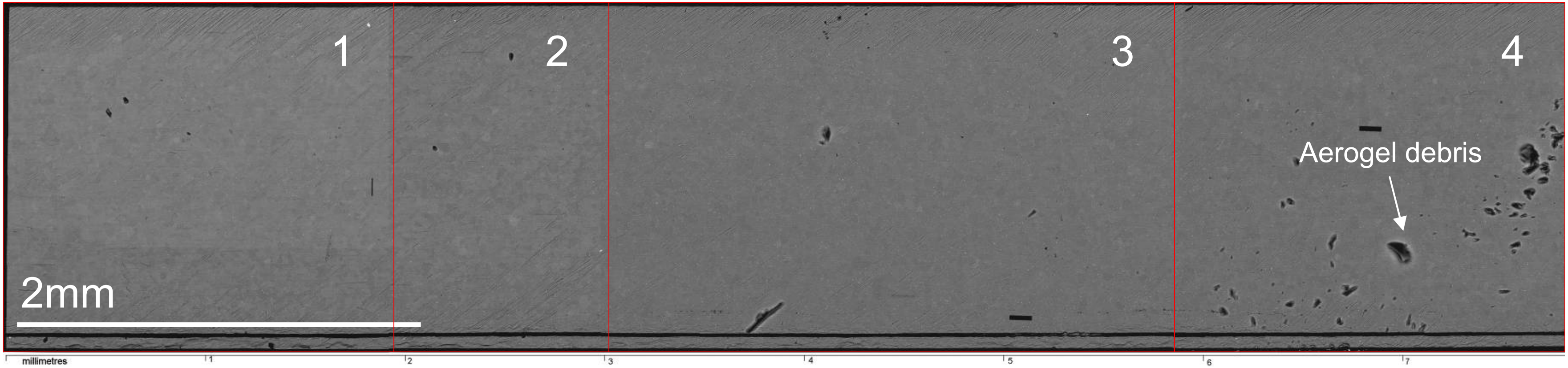
Automation of high magnification image acquisition from the curved ends of the foil could not be performed due to major differences in height (> 500 microns variation in working distance).

Conclusion: The ‘Gulliver’ sample mounting method is not invasive or damaging to the foil, but must be limited to surveys of small areas on strongly curved foils.

A large number of images were extracted for compilation of a reference library of foil surface textures, mechanical linear fabrics, percussion marks, compositional and internal structural features of the foil, and the appearance of small aerogel fragments. These images are available for circulation and discussion among PET.

A second, intensive suite of campaigns was undertaken using secondary electron images, with manual correction of working distance between frames.

The Gulliver method works well for initial examination, but if high magnification automation of the entire foil is required, the foil ends should be clamped down to prevent focus problems and image dimension mismatch due to curvature.



Example of four stitched high resolution Backscattered electron montages created by automated stage movement and image acquisition. Area in this image is c. 12.4 mm^2, pixel spacing in original images is less than 240nm. This area was searched for craters of 5 microns and greater diameter. None were found. Subsequent imaging of this area using secondary electrons found one crater of 2.4 microns diameter.

C2125N,1

Results from SEI campaigns – low mag.

Two campaigns of secondary electron imagery at low (x300) magnification were performed at the NHM, covering c. 34.6 square mm. Approximately 130 high resolution images were acquired (20.8 square mm), extracted for future reference. Four features were investigated, three (Walton features 2, 3 and 4) were identified as impact features. Two lay outside the area of the previous BSE montages, and one very small feature (<3 microns diameter) within the area of the previous montage 4.

The three features identified as of impact origin had strong edge-effect secondary emission from the crater lip, enabling easy recognition at x300 magnification in images of 2048 pixels lateral dimension, taken with 10 micro-second pixel dwell time (20kV or 15kV accelerating voltage, beam current less than 40 picoAmperes).

Walton feature 2 was further investigated by high magnification imagery, stereo tilted SE images for topographic reconstruction, X-ray mapping, extraction of spectra from the stored map data-set (c. 120MB) and acquisition of point and area spectra from the crater and surrounding areas. Spectra were also acquired from features 3 and 4.

SEI low magnification survey image showing 5.7 by 4.0 micron crater.

Image is 419 microns, 2048 pixels wide with c.200nm pixel spacing.

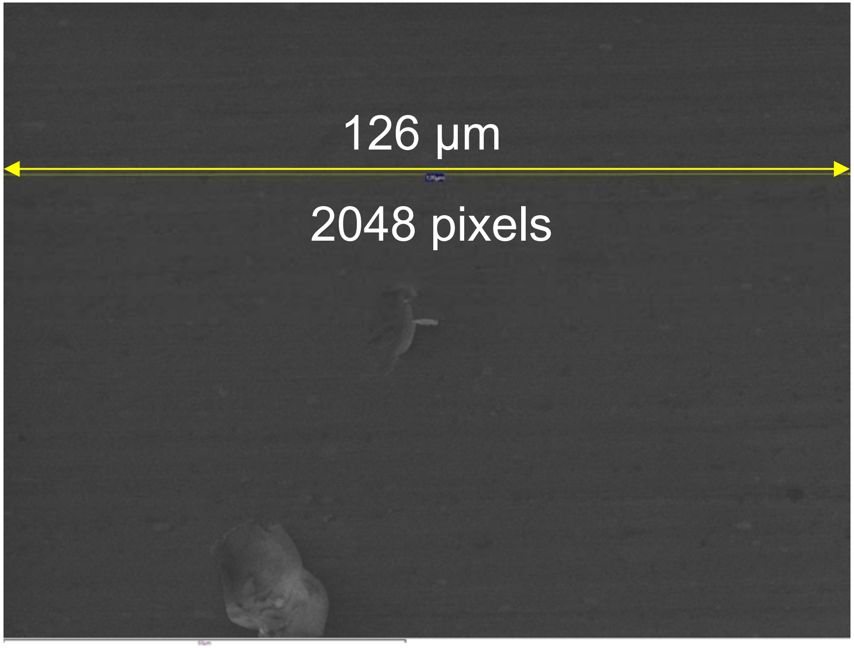
Results from SEI campaigns – high mag.

Five automated campaigns of secondary electron imagery at high (x1000) magnification were performed at the NHM, covering 5.75 mm^2 in 108, 88, 108, 108 and 108 frames respectively. Secondary electron images were taken at 2048 pixels lateral dimension across a field of 126 microns width (c. 62 nm spacing), with 10 micro-second pixel dwell time using 20kV accelerating voltage. Topographic features < 600nm were resolved on scratched foil areas.

No impact craters were found in the 5 mm^2.

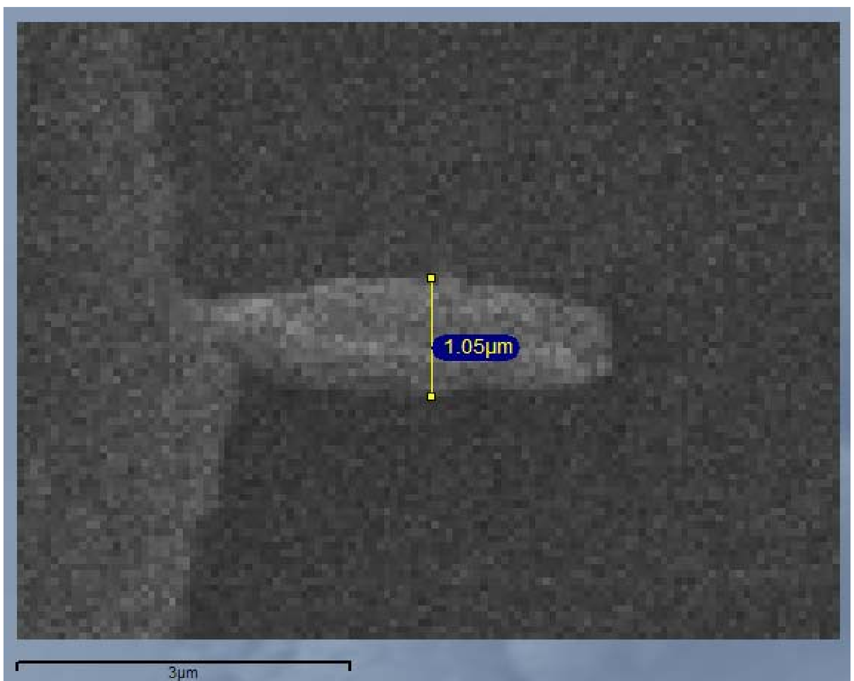
C2125N,1

Stardust foil C2125N,1



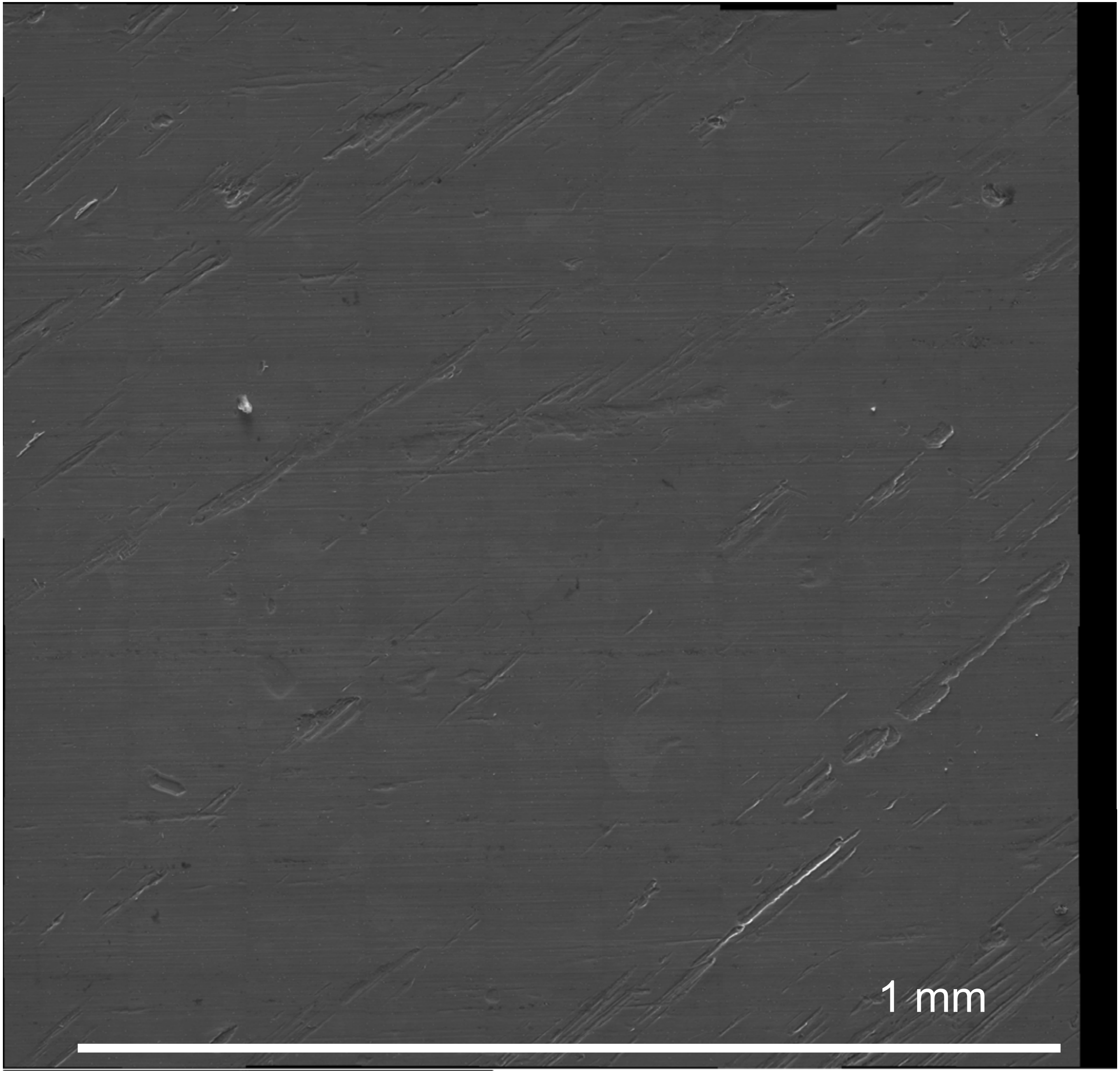
Full single image

High magnification (x1000) secondary electron images with a high pixel number (2048 pixels across 126 microns field of view) allow recognition of features as small as 200nm. The ‘edge effect’ of the crater rim makes hypervelocity impact craters easy to find.



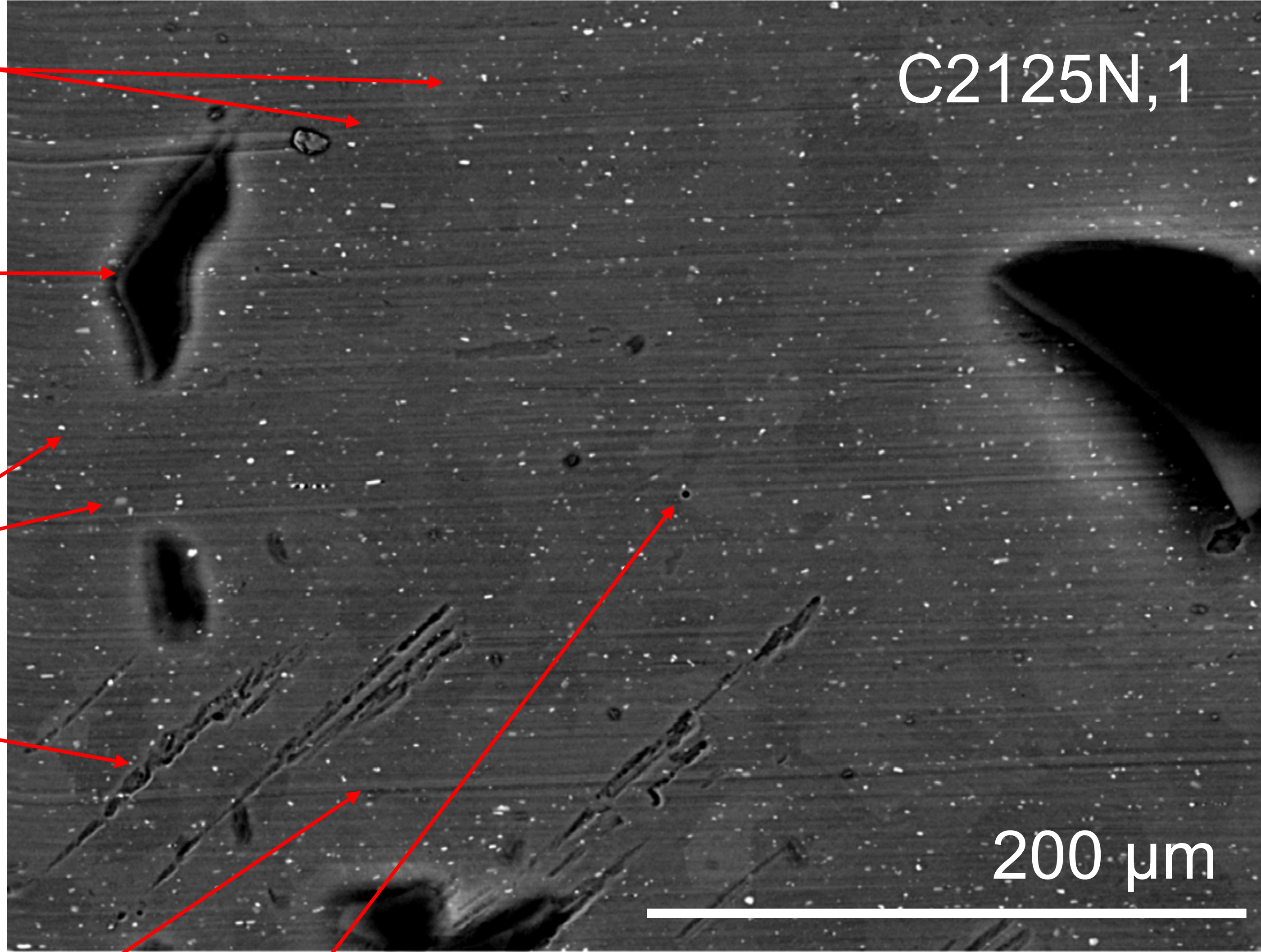
Enlargement of centre of image

C2125N,1



Automatic acquisition and stitching of a montage of 108 secondary electron images, each of 2048 pixels width.

An entire run takes about 2 hours to acquire data, and about 2 minutes to create the montage. Individual frame images are examined for location of impact features



Crystallographic grain contrast

Aerogel fragment

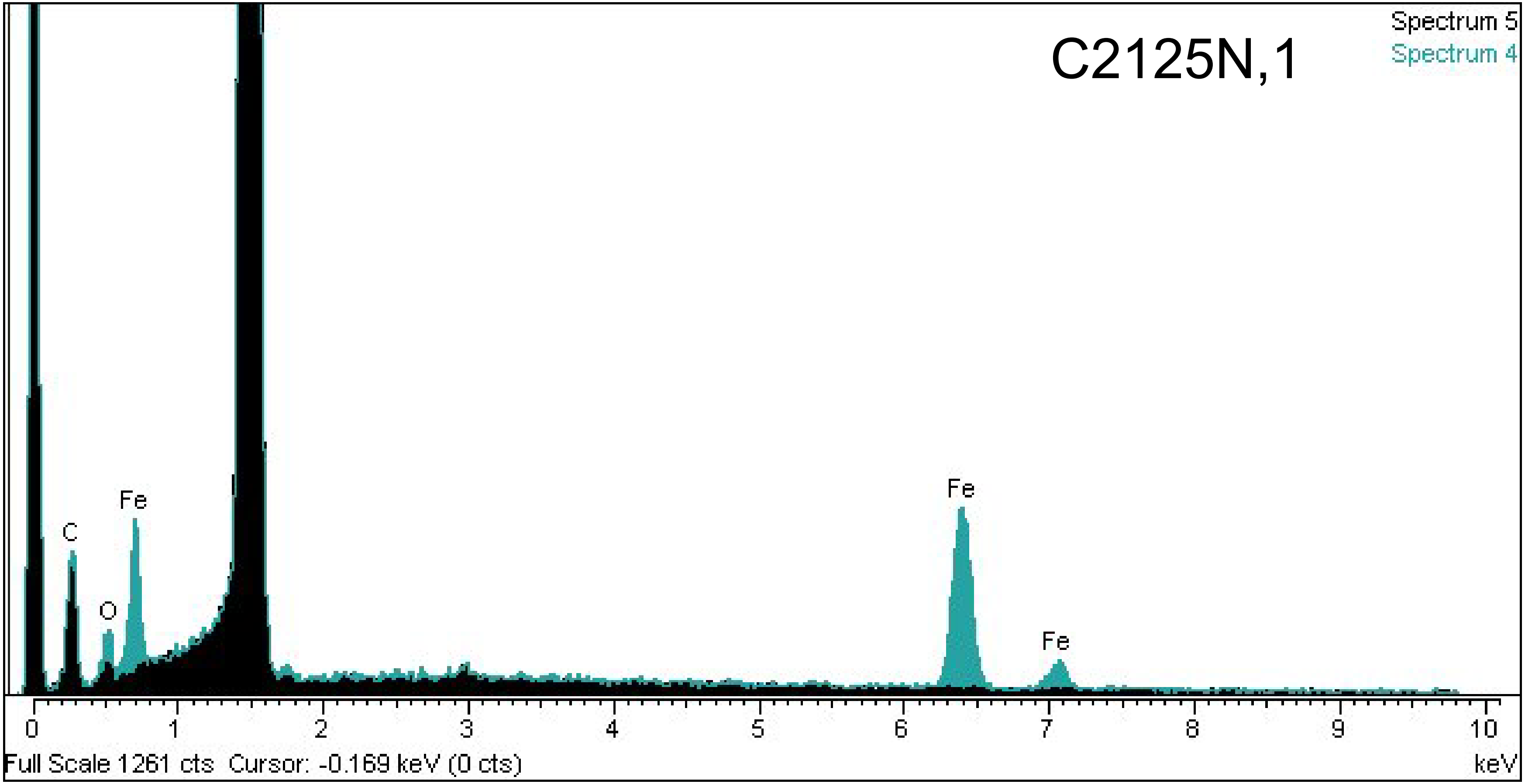
Fe-rich inclusions

Deep oblique scratch

Shallow longitudinal ridge and furrow

Impact crater (Feature 3, 2.4 microns diameter)

Features seen in backscattered electron images



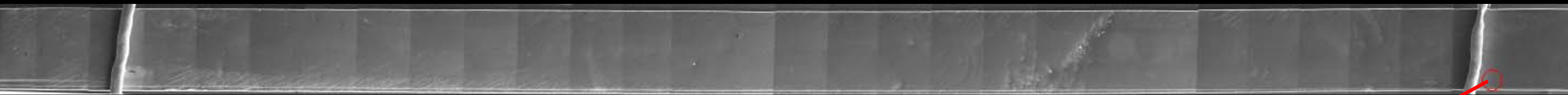
Fe-rich inclusion (shown in **pale blue**) in Aluminium alloy **(black)** shows no enrichment in Sulfur (as found in the impact feature 3), but minor Oxygen is present.

Conclusion: Fe in alloy may be a nuisance, but is unlikely to be confused with Fe sulfide or silicate. Magnetite shows higher Oxygen than in the above spectrum.

C2125N,1

impact feature 2

33.03 mm length (1.67 mm height)

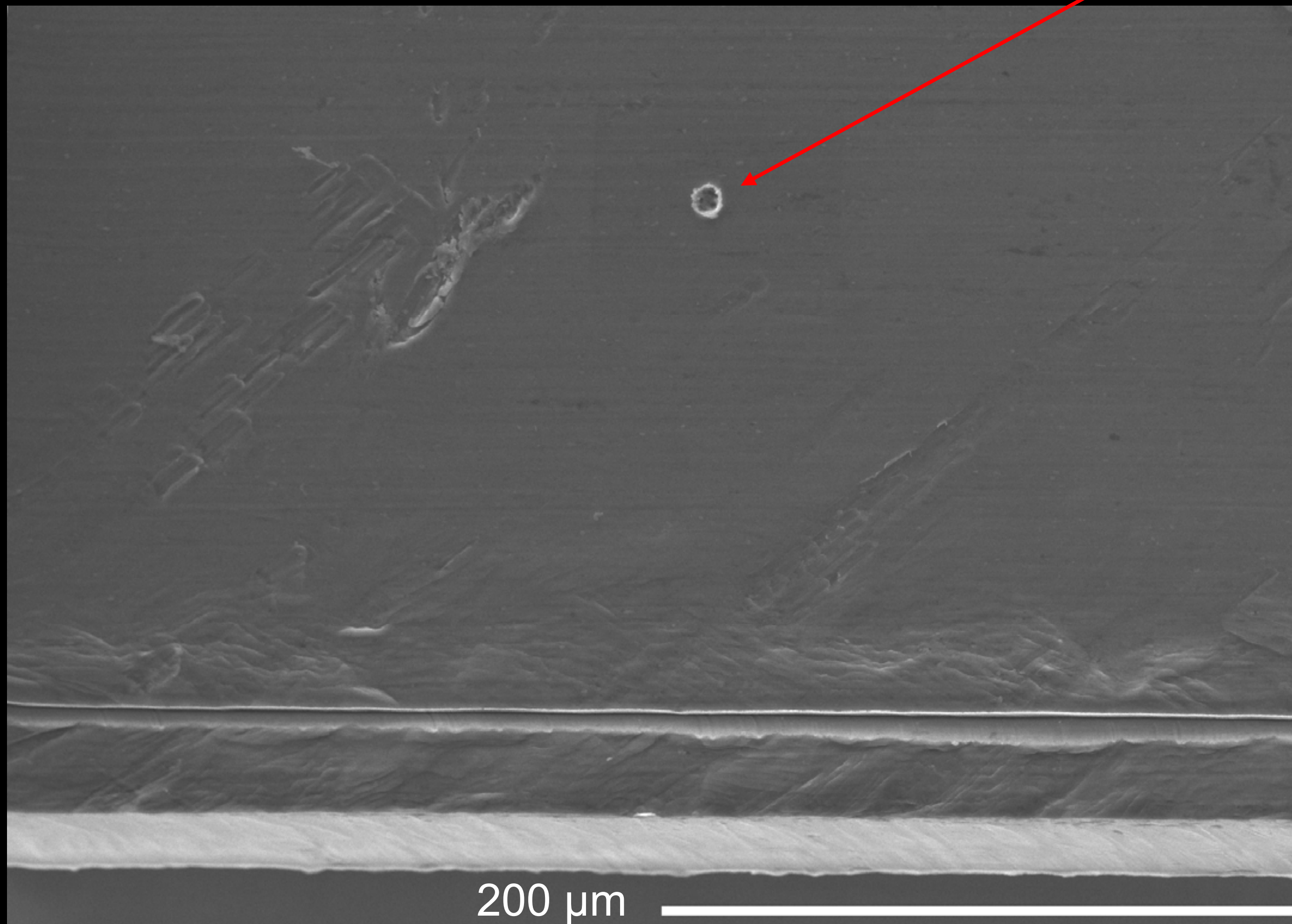


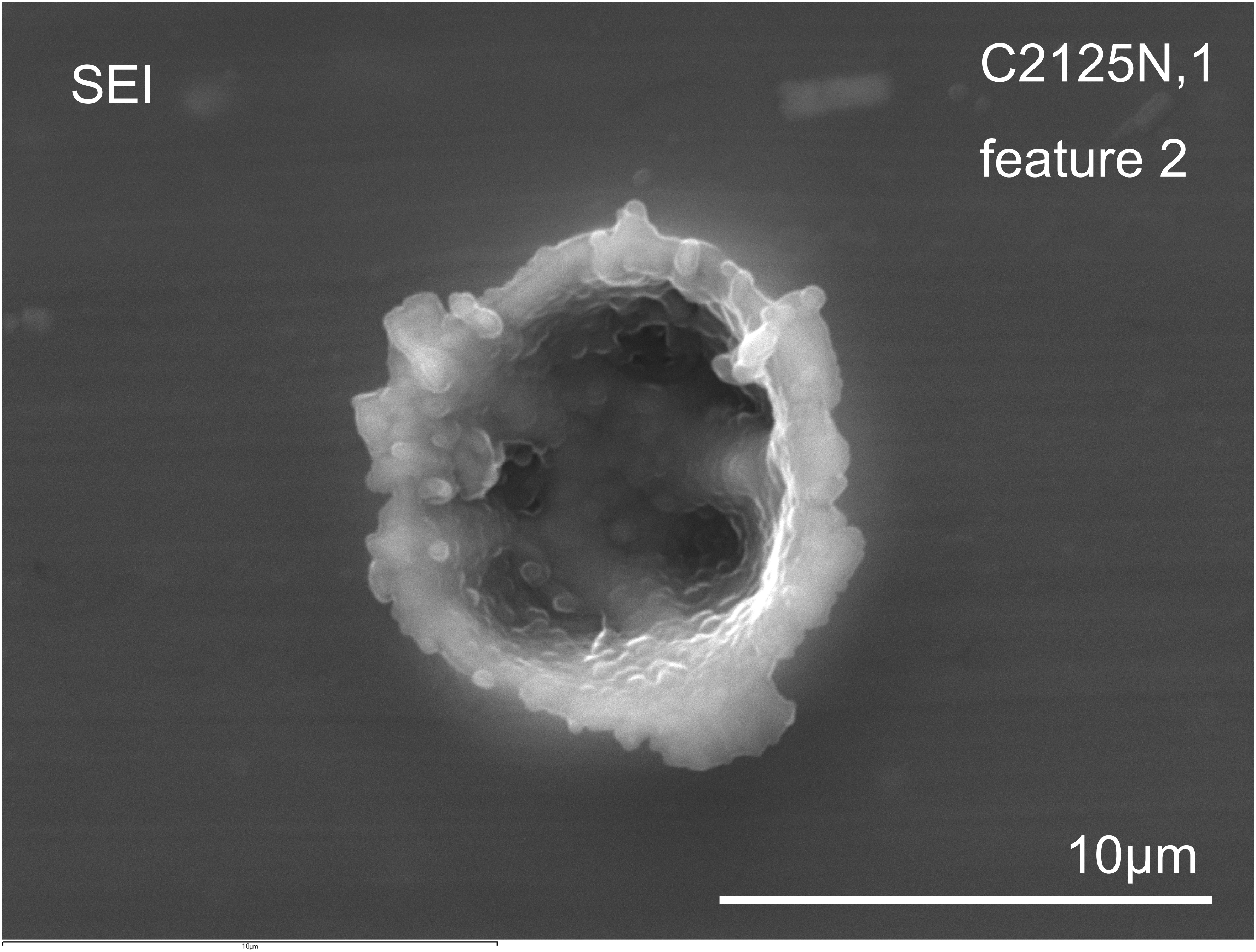
Whole foil with restraining Sn wires.

Impact feature of approximately 9 microns diameter

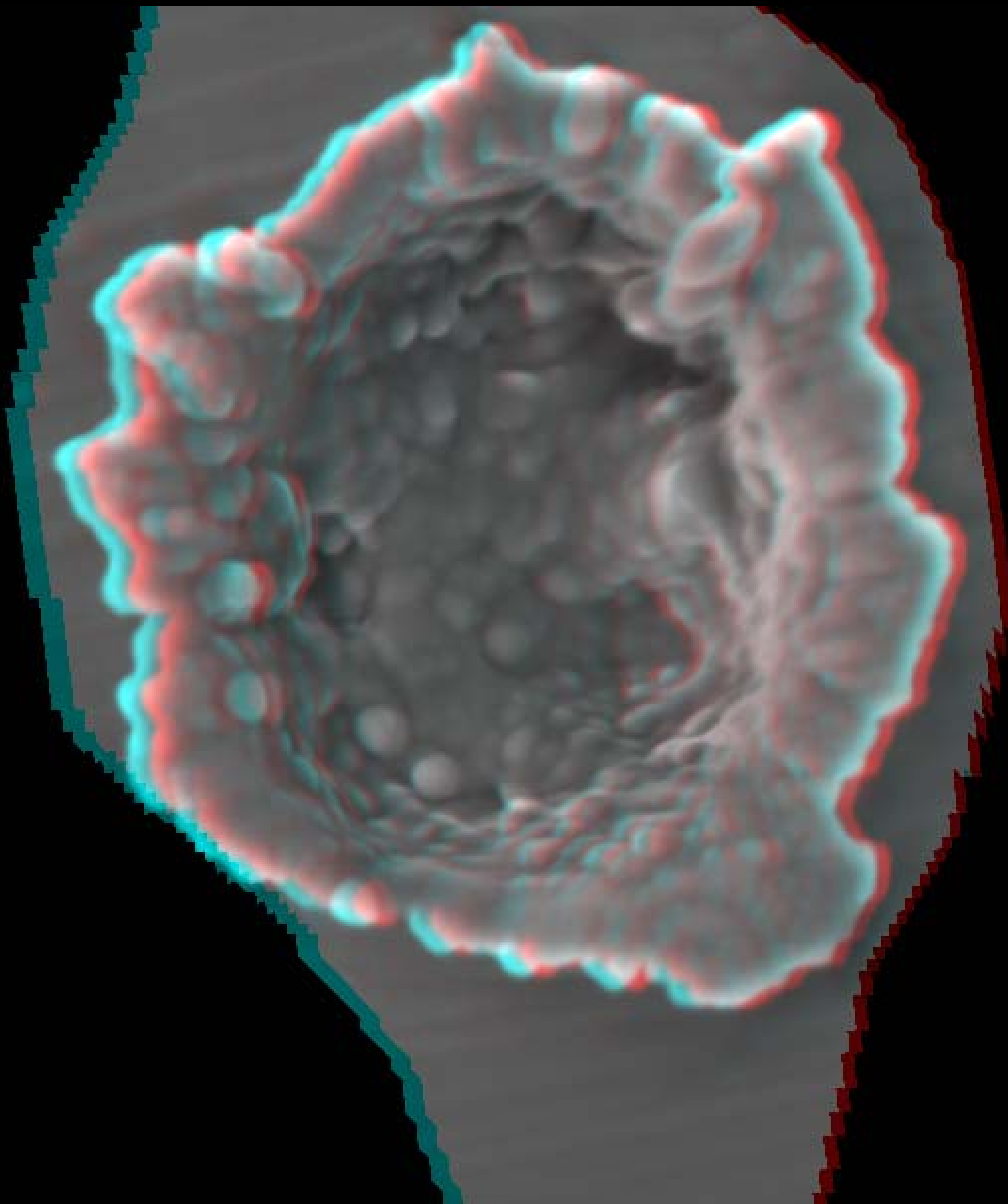
Cut mark on foil →

Cut edge of foil →





SEI
C2125N,1
feature 2
10µm



C2125N,1

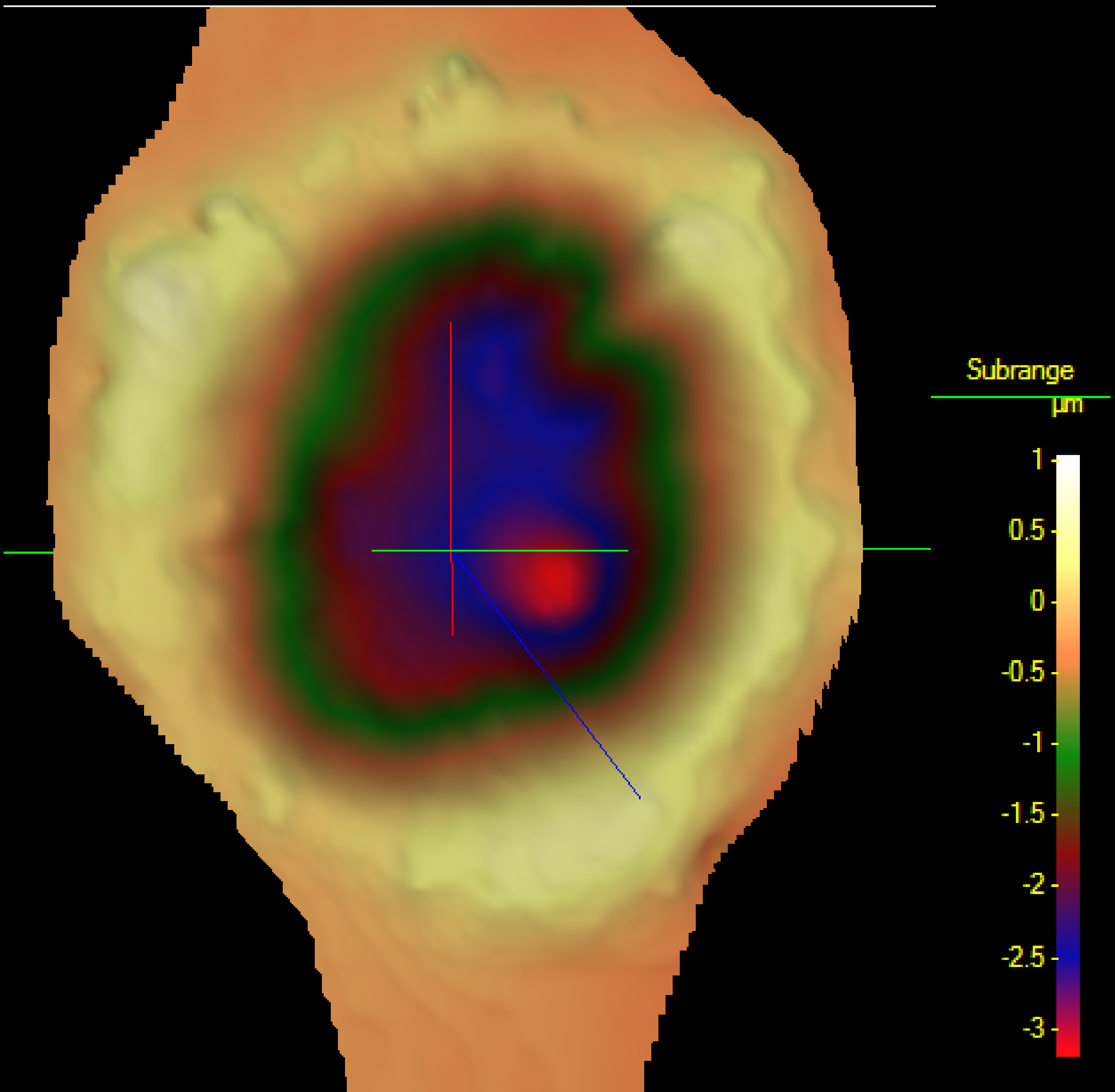
feature 2

Stereo anaglyph

C2125N,1

feature 2

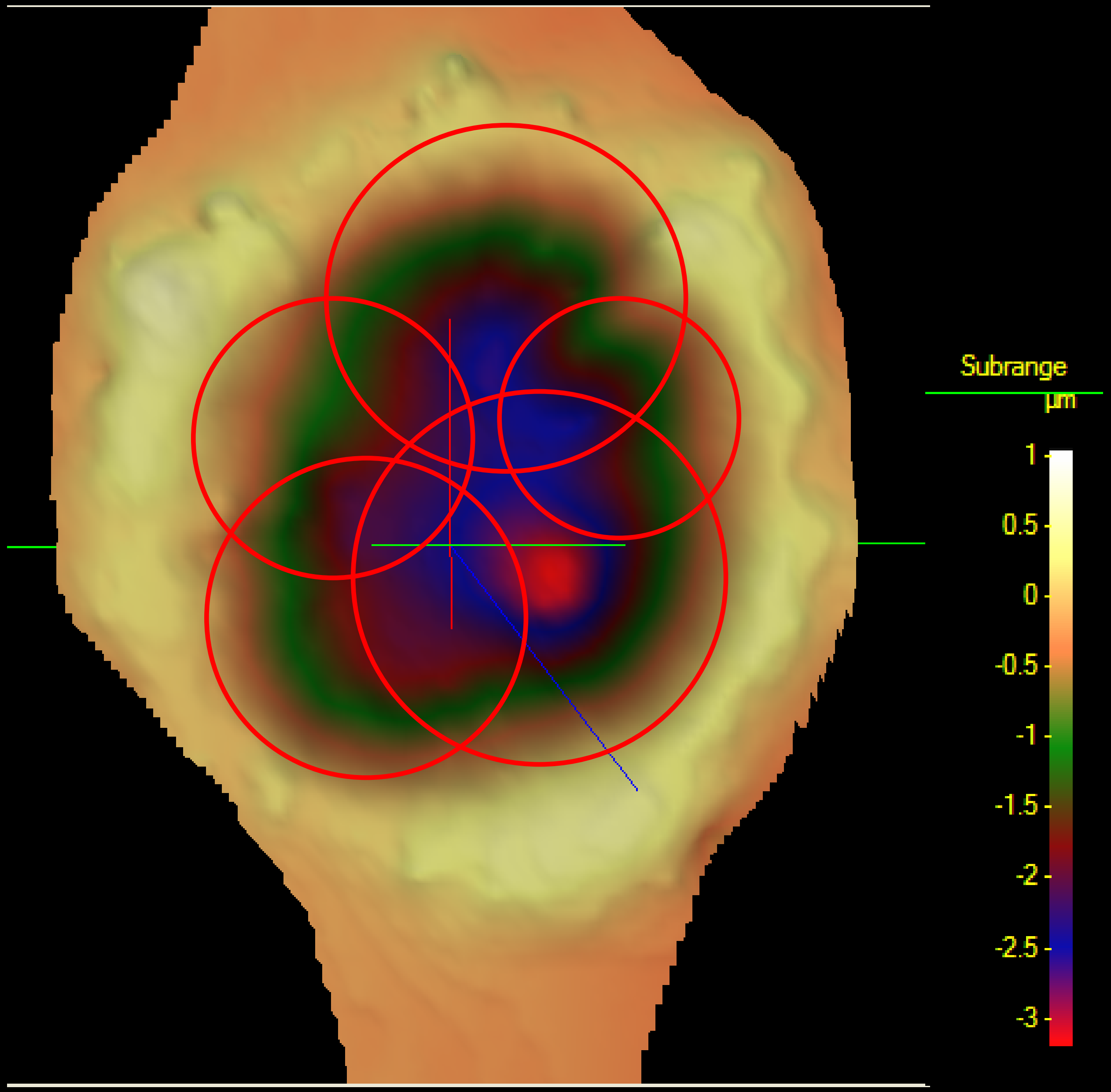
Depth model



C2125N,1

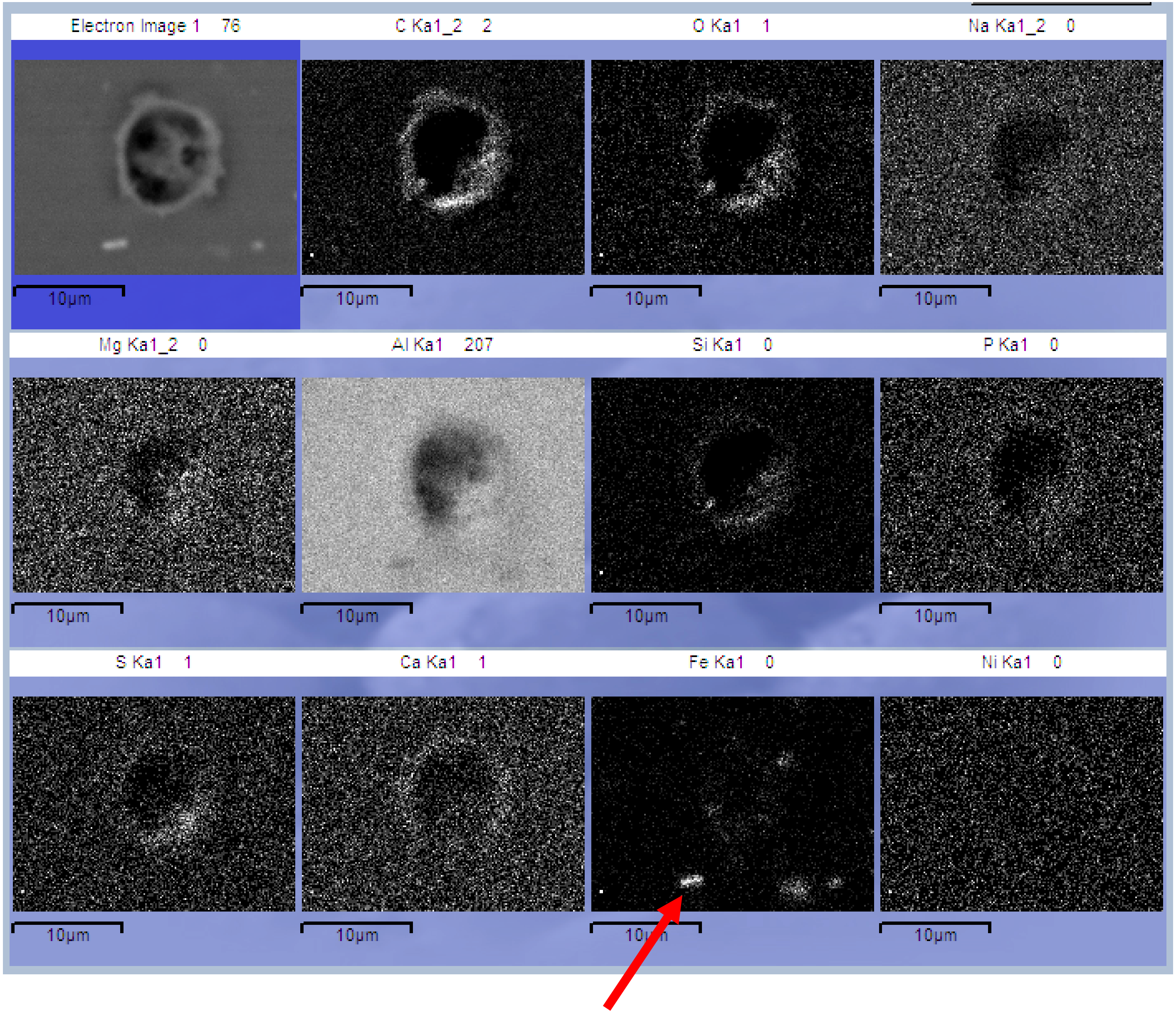
feature 2

Depth model with crater overlap centres

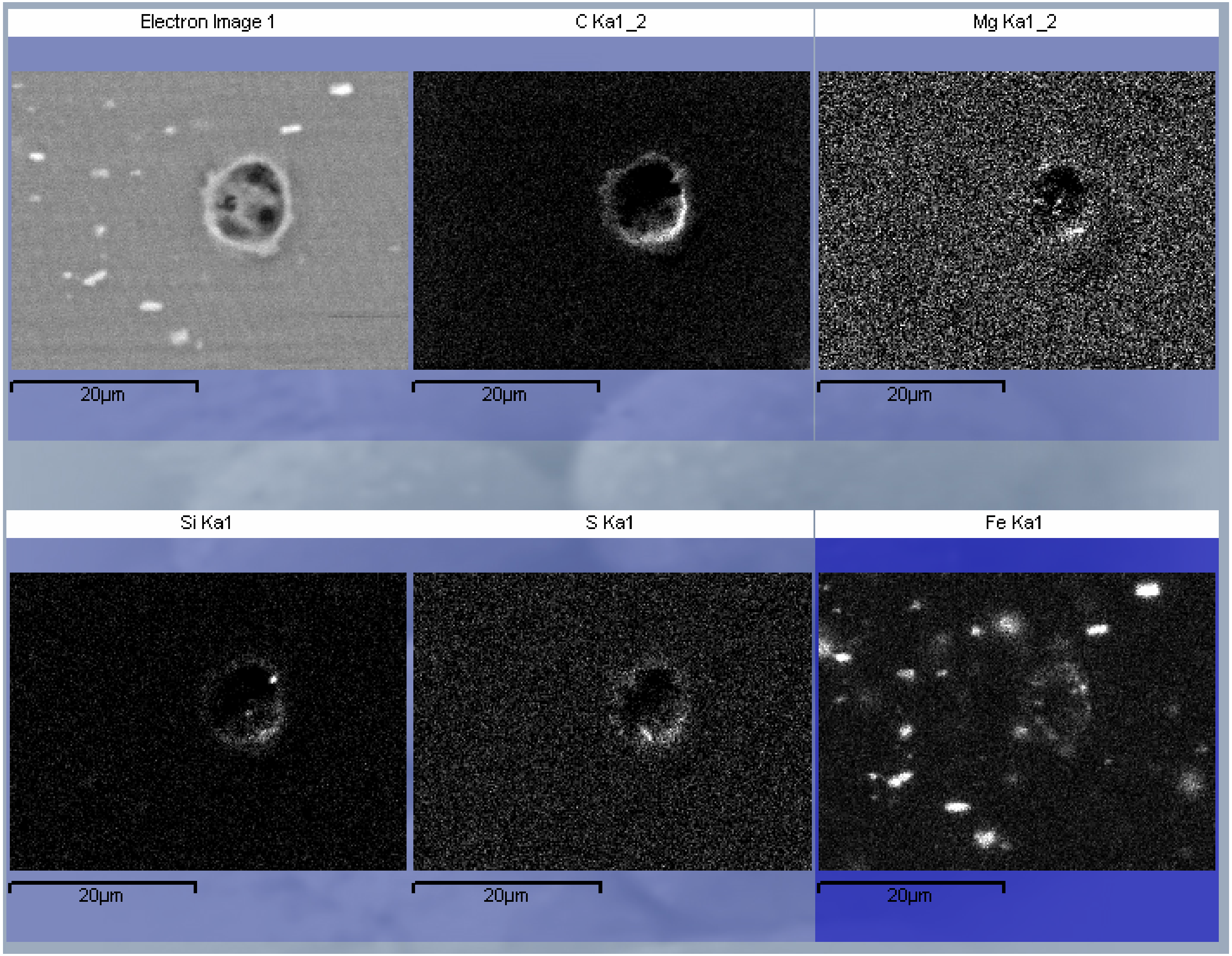


C2125N,1 feature 2

X-ray maps



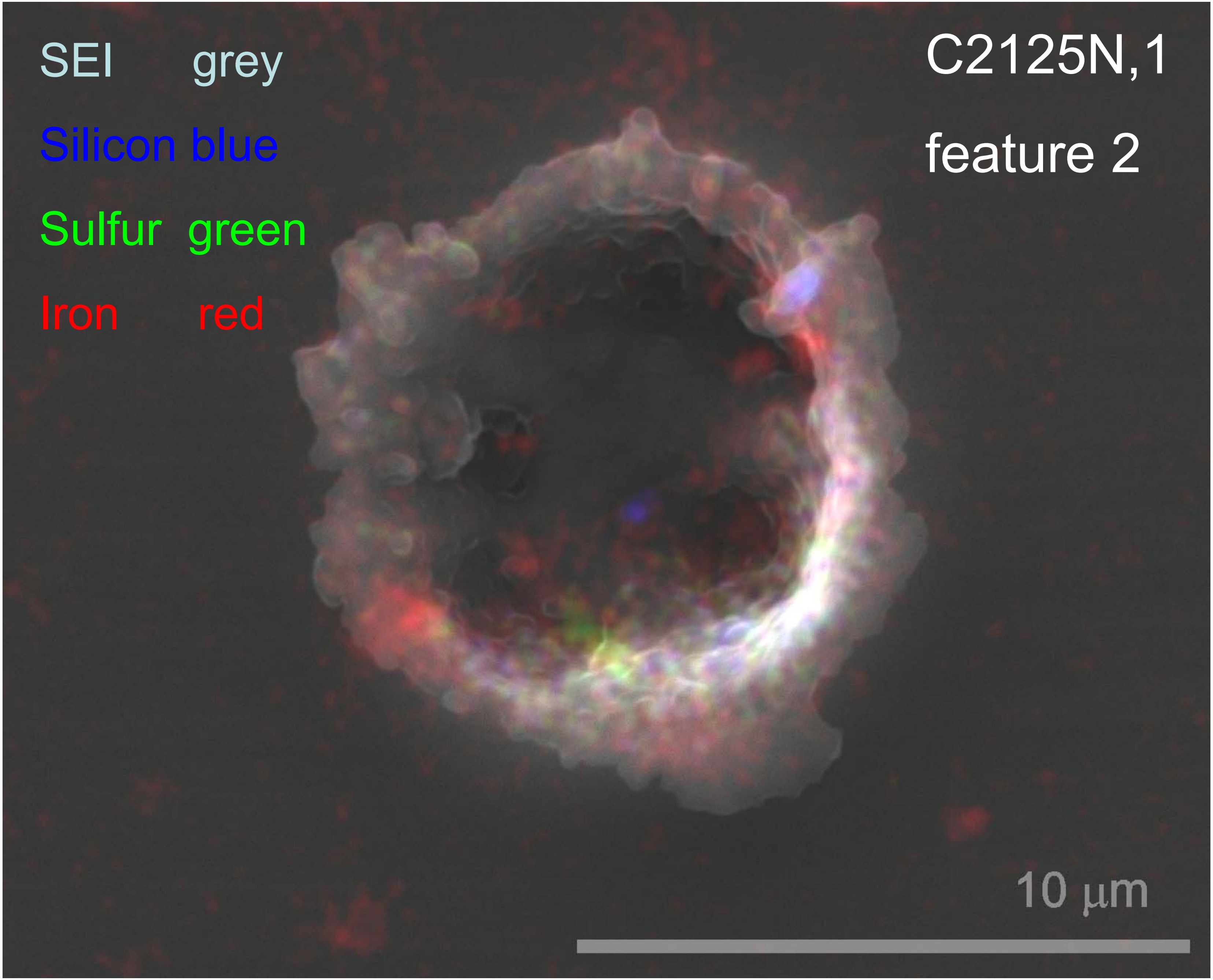
Note large Fe-rich inclusion outside crater

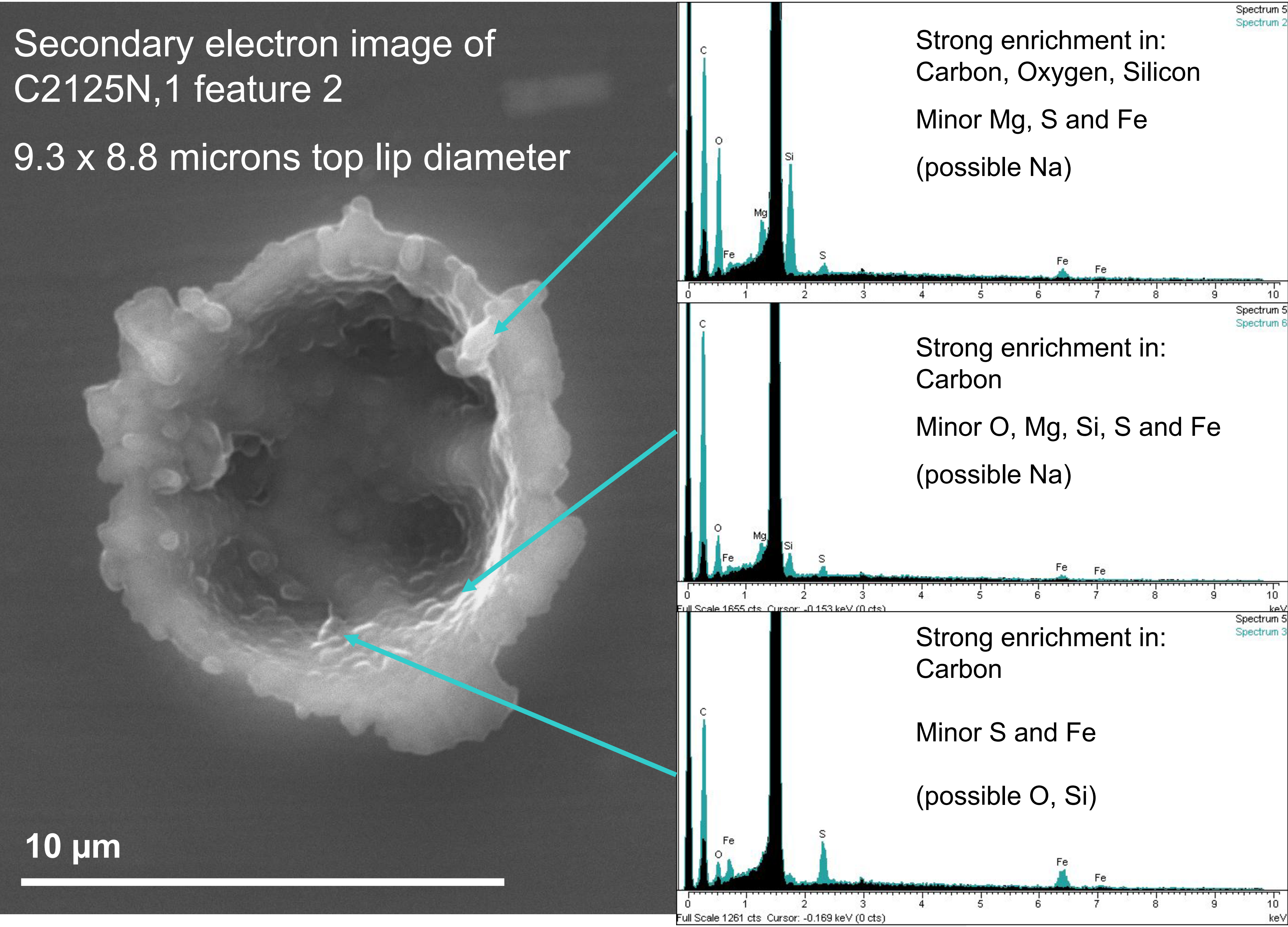


C2125N,1 feature 2

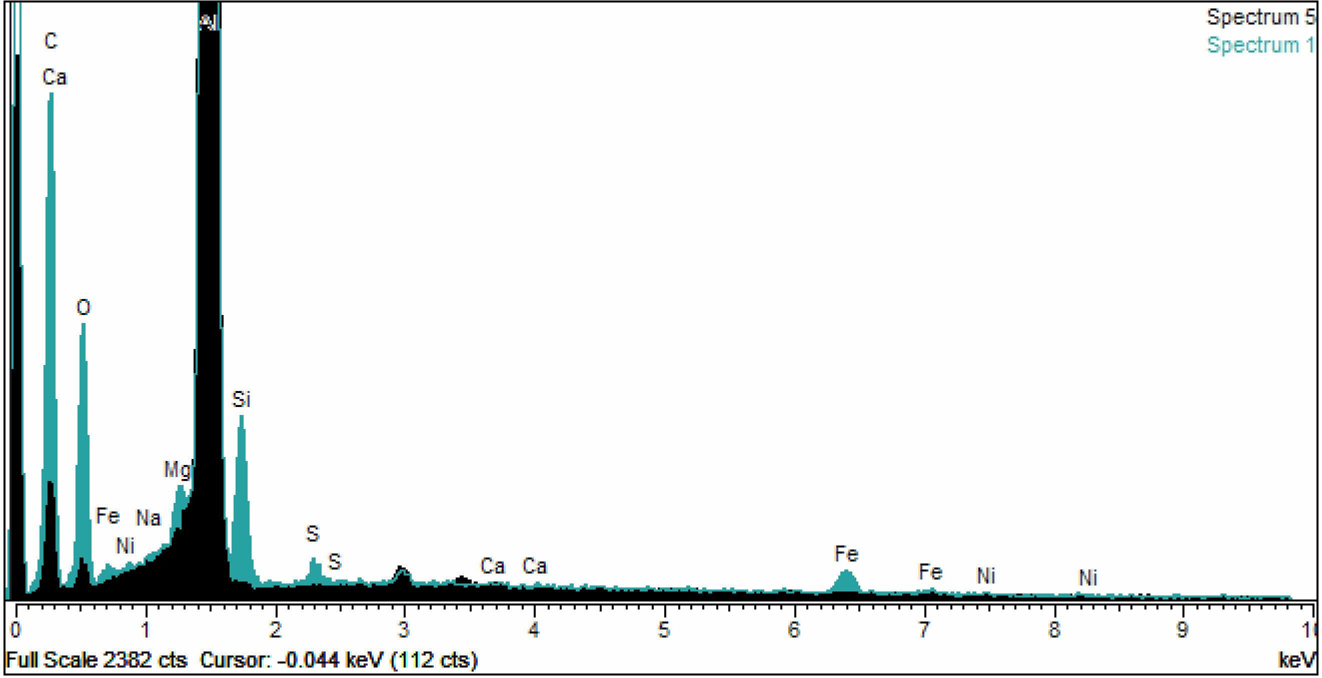
X-ray maps

C, Mg, Si, S and Fe-rich areas within crater


SEI grey
Silicon blue
Sulfur green
Iron red
C2125N,1
feature 2
10 µm



Secondary electron image of C2125N,1 feature 2
9.3 x 8.8 microns top lip diameter
10 µm
Spectrum 5
Spectrum 2
Strong enrichment in:
Carbon, Oxygen, Silicon
Minor Mg, S and Fe
(possible Na)
Spectrum 5
Spectrum 6
Strong enrichment in:
Carbon
Minor O, Mg, Si, S and Fe
(possible Na)
Spectrum 5
Spectrum 3
Strong enrichment in:
Carbon
Minor S and Fe
(possible O, Si)
Full Scale 1261 cts Cursor: -0.169 keV (0 cts)
keV



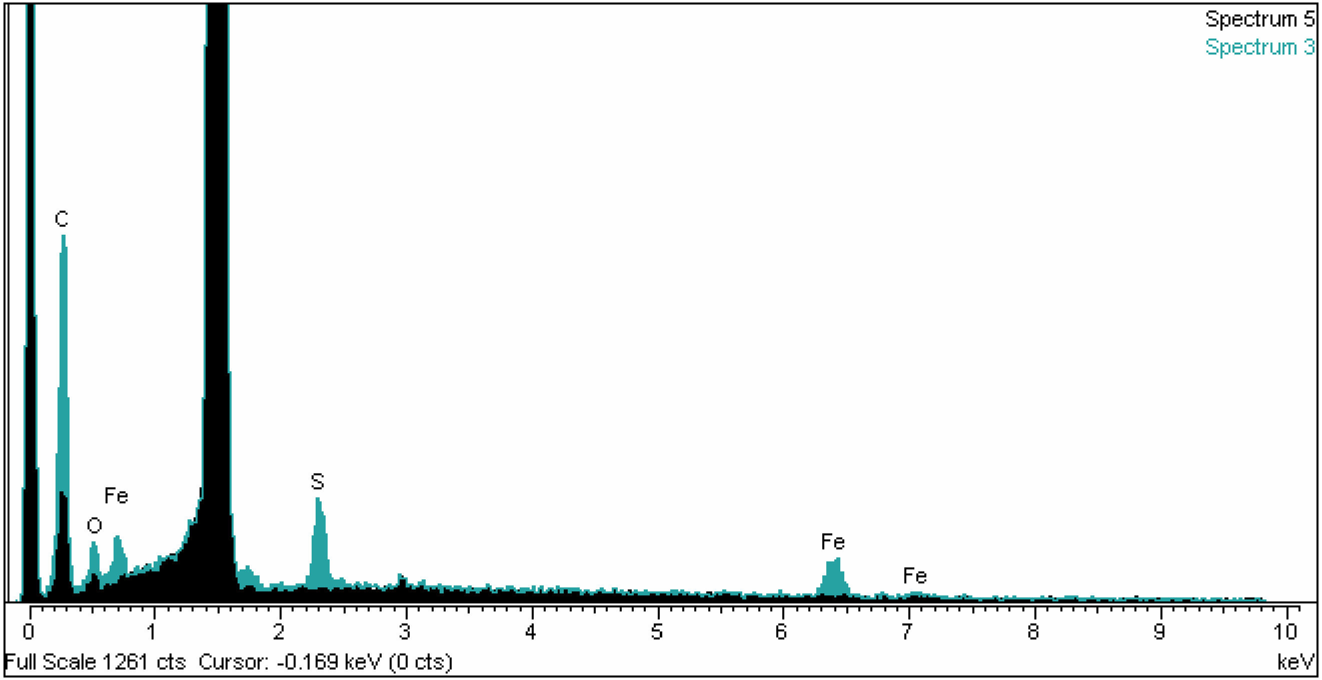
C2125N,1

feature 2

Element	Weight%	Weight% sigma	Atom%	Oxide %	Atoms
Na	trace	0.6	bdl	bdl	bdl
Mg	14.7	0.5	13.0	24.4	5.1
Si	25.0	0.5	19.1	53.4	7.5
S	2.7	0.2	1.8	6.7	0.7
Ca	trace	0.4	bdl	bdl	bdl
Fe	10.8	0.6	4.2	13.9	1.6
Ni	trace	0.5	bdl	bdl	bdl
O	45.6	0.7	61.2		24.0

C2125N,1

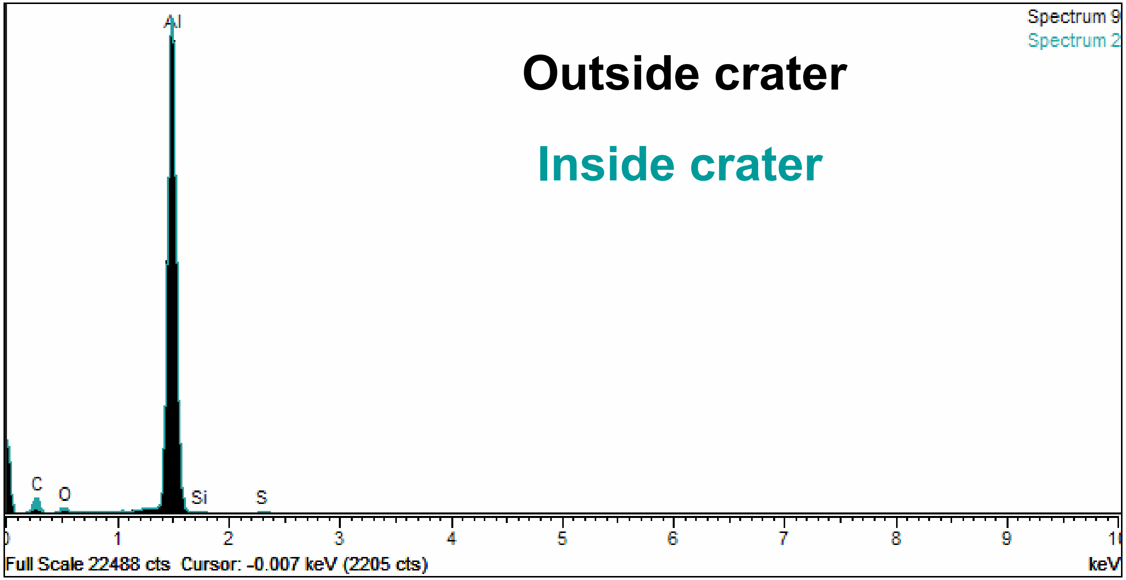
feature 2

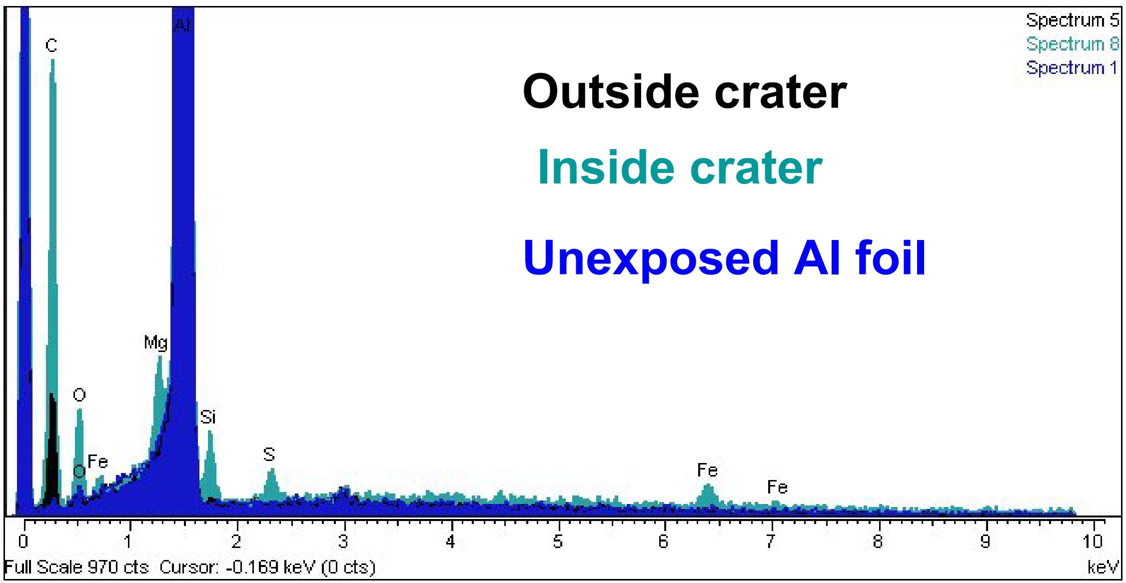


sp5

Element	Weight%	Weight% sigma	Atomic%
S	32.2	4.0	45.3
Fe	67.8	4.0	54.7
Totals	100.0		

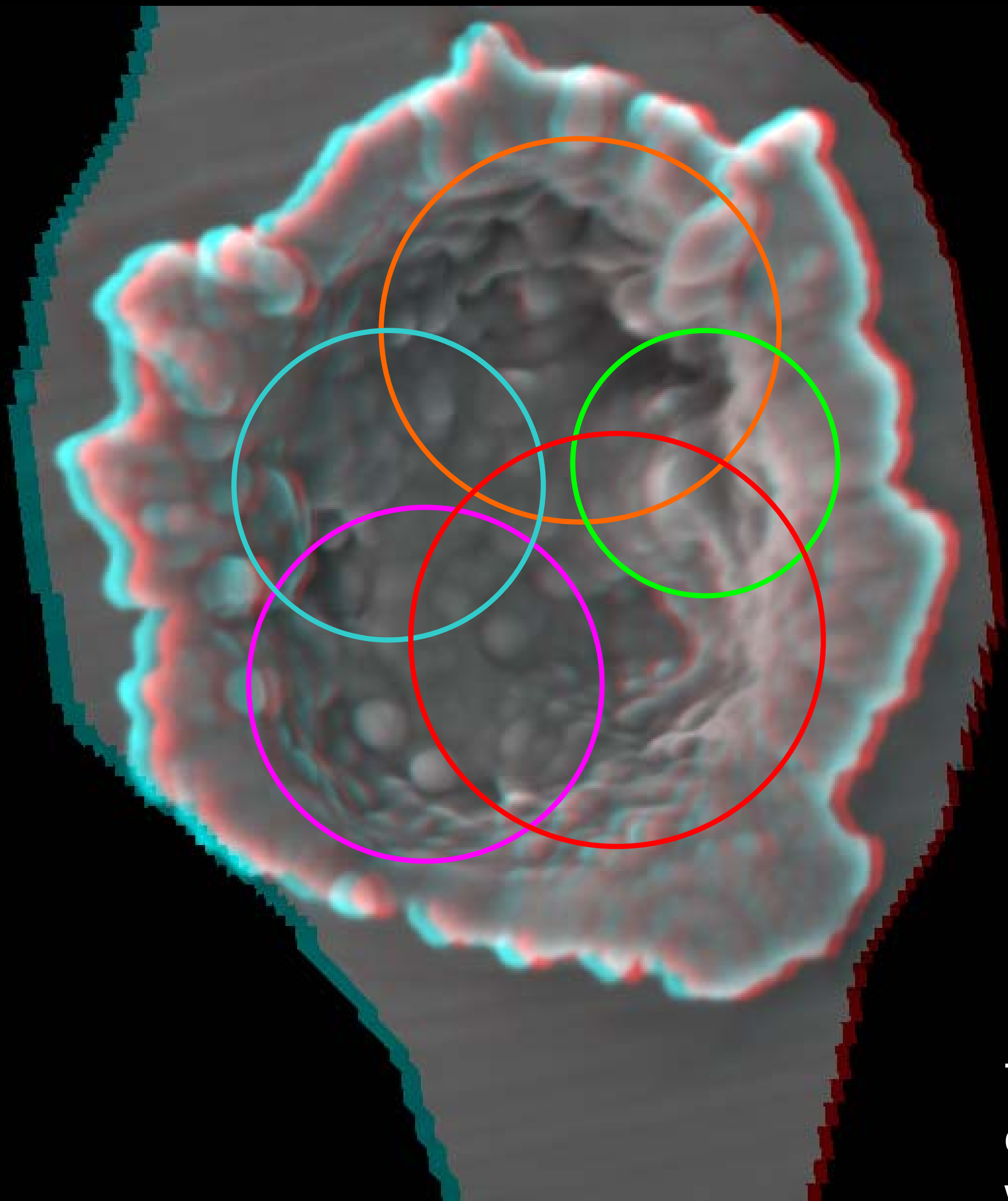
Carbon-rich residue in C2125N,1 feature 2





Comparison of spectra from map data taken inside and outside of the crater show an increase in carbon count rate, even in a full scale spectrum. This apparent excess cannot be explained by sample geometry alone.

A thin Carbon film (shown in **black**) is deposited during prolonged electron beam exposure of clean Al alloy surfaces (unexposed foil shown in **dark blue**). However, carbon levels inside the crater (shown in **pale blue**) are much higher.



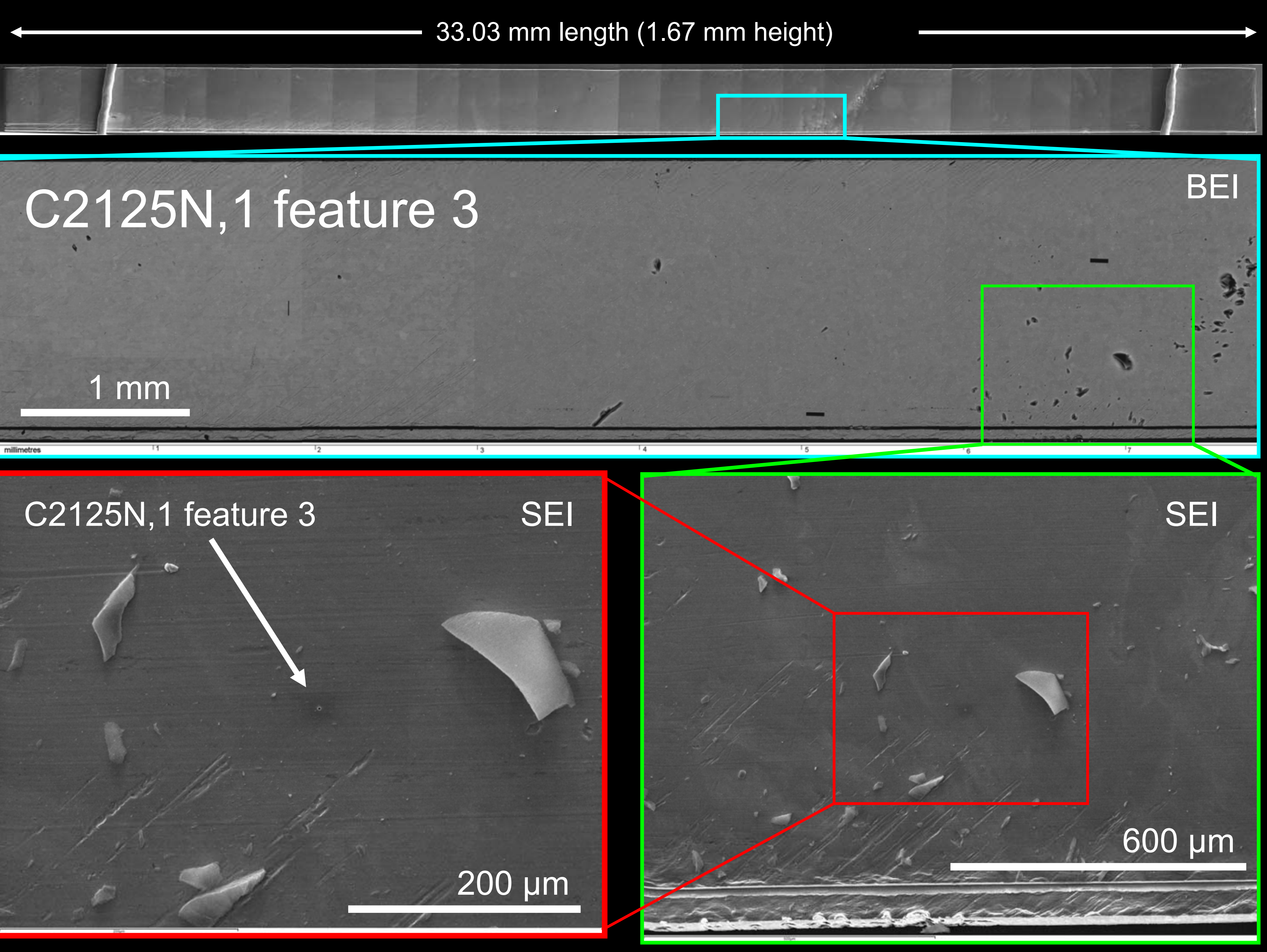
C2125N,1 feature 2

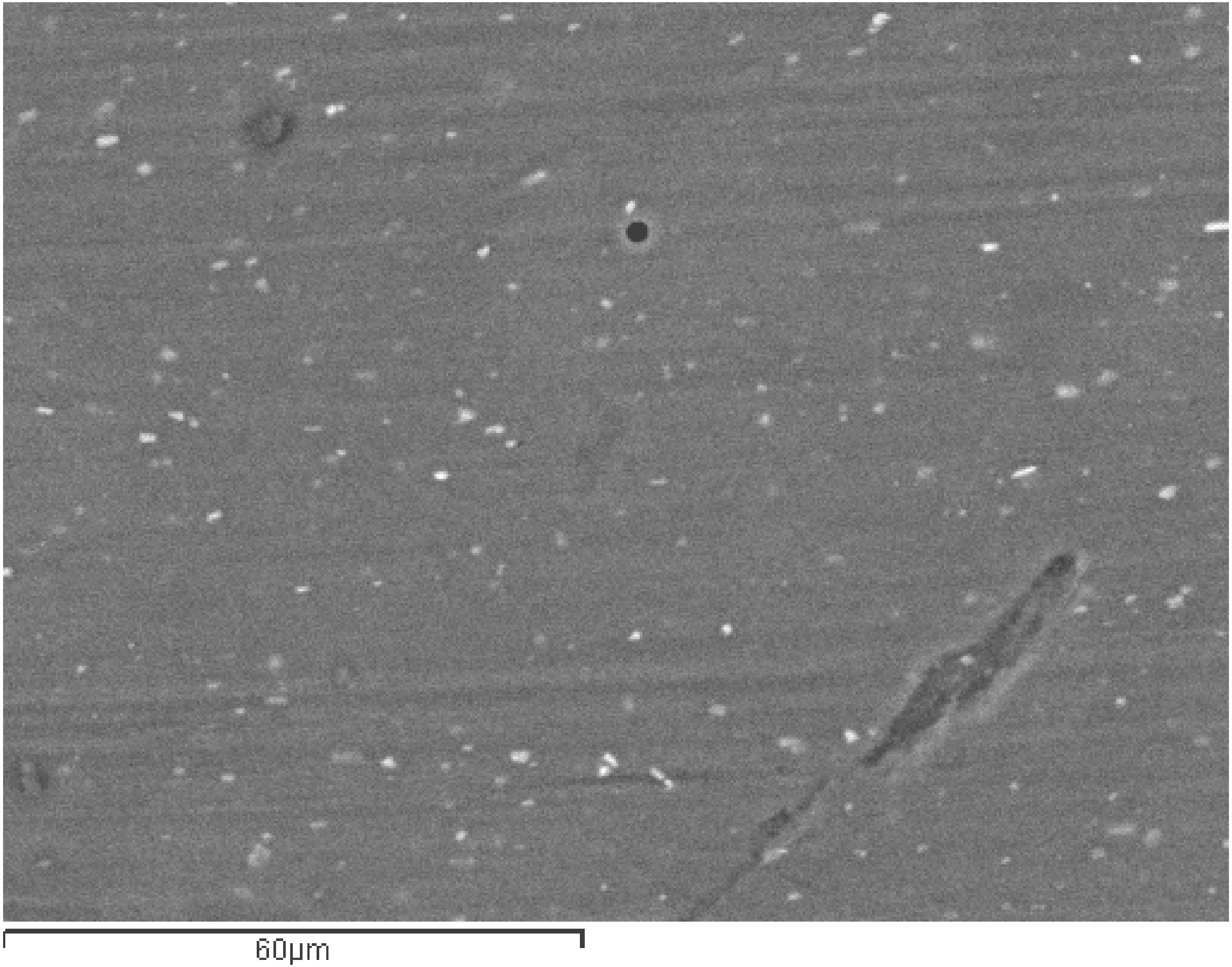
Stereo anaglyph with crater overlap

Assume all silicates = 3.2 gcm^{-3}

Crater diameter	particle diameter	mass
4.37 microns	790nm	0.8 pg
3.03 microns	540nm	0.27 pg
4.73 microns	850nm	1 pg
4.06 microns	730nm	0.65 pg
3.52 microns	630nm	0.42 pg
+ one more?	850nm	1 pg

Total mass 4.14 pg in an aggregate of c.4 microns diameter gives a whole particle density of 0.12 gcm^{-3}


33.03 mm length (1.67 mm height)
C2125N,1 feature 3
BEI
1 mm
millimetres
C2125N,1 feature 3
SEI
200 µm
SEI
600 µm

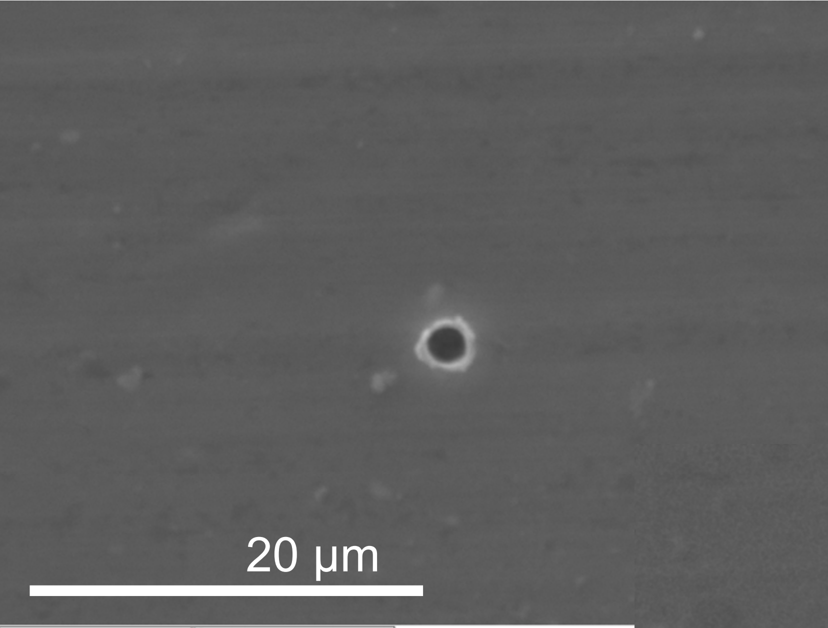


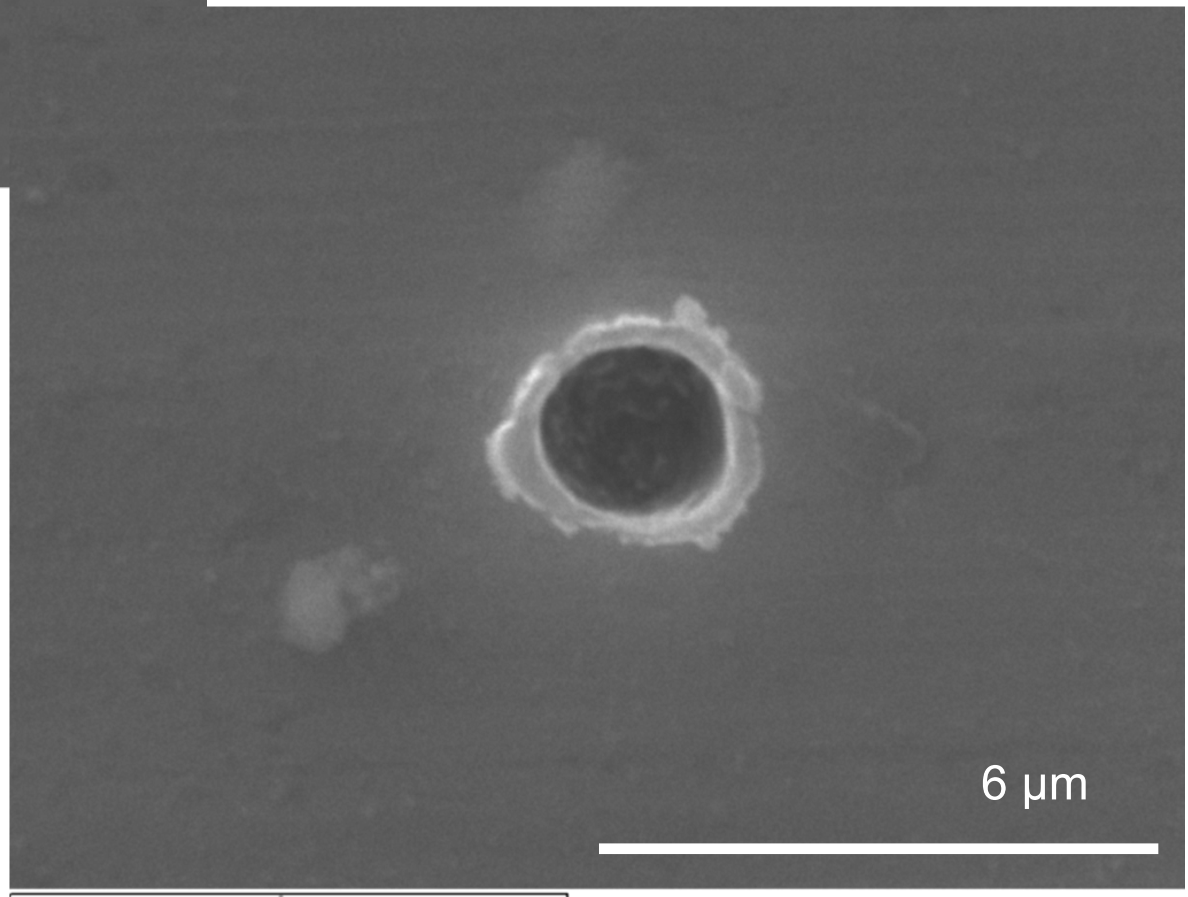
BEI frame 281 from automated montage run 4 (ak060214b.ipj), showing a dark circular feature, subsequently identified as a 2.4 micron diameter impact crater (C2125N,1 feature 3), during secondary electron imagery campaign 1 (ak060302).

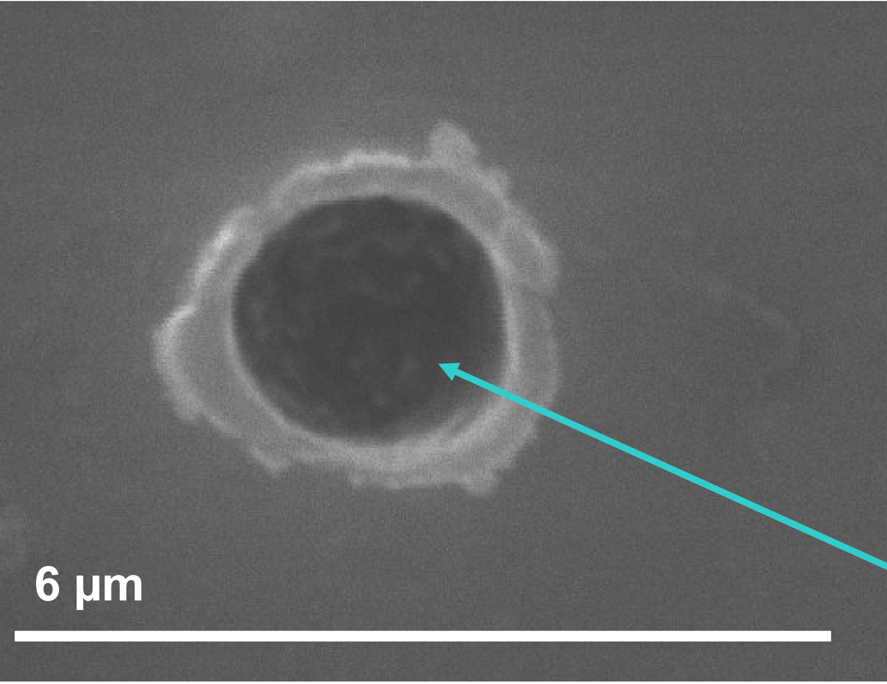
C2125N,1 feature 3

2.41 microns top lip diameter

Secondary electron images





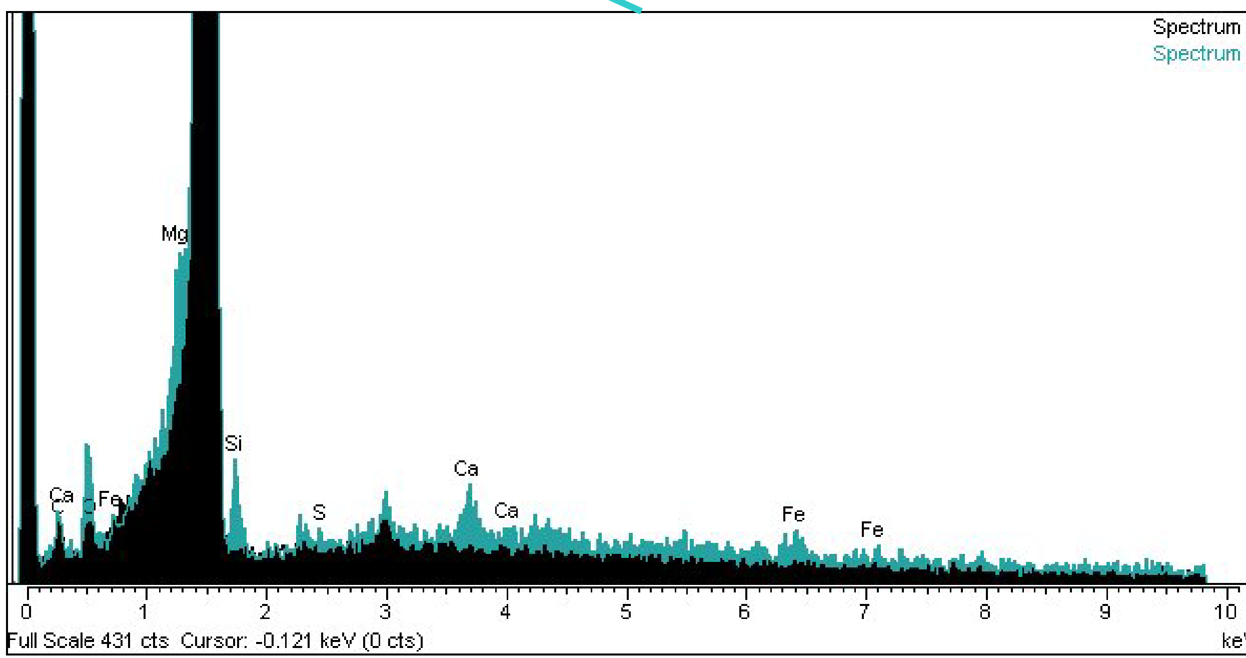


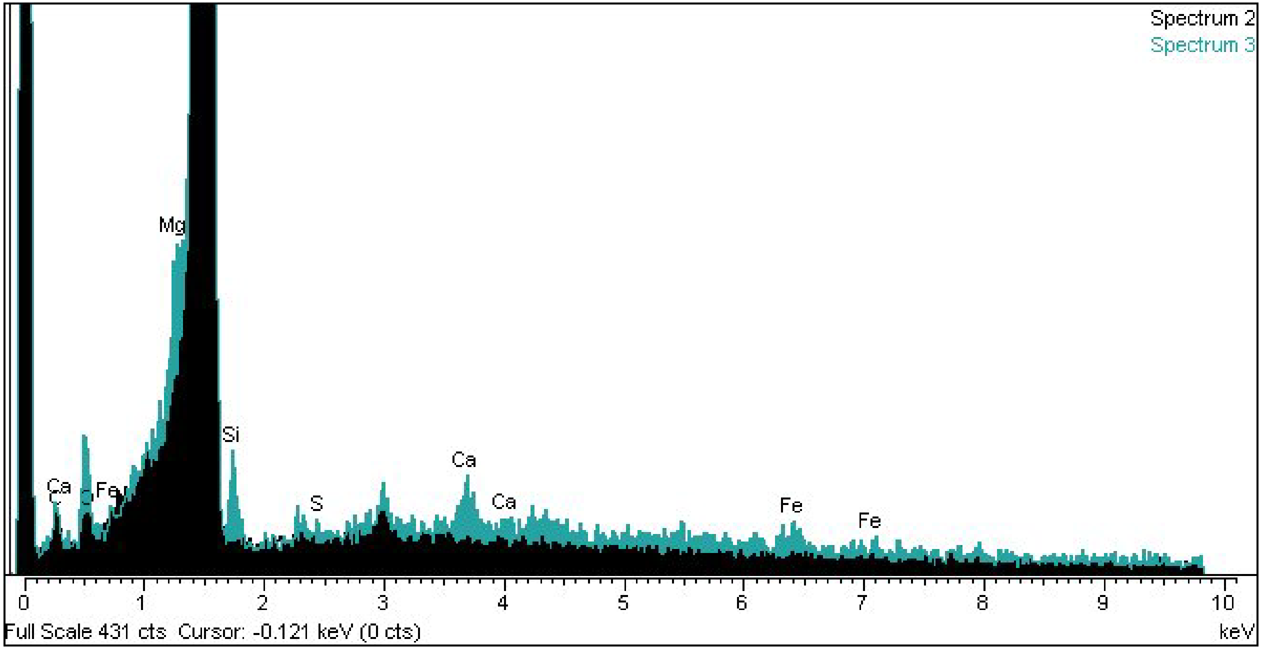
C2125N,1 feature 3

2.41 microns top lip diameter

Secondary electron image and energy dispersive X-ray spectrum

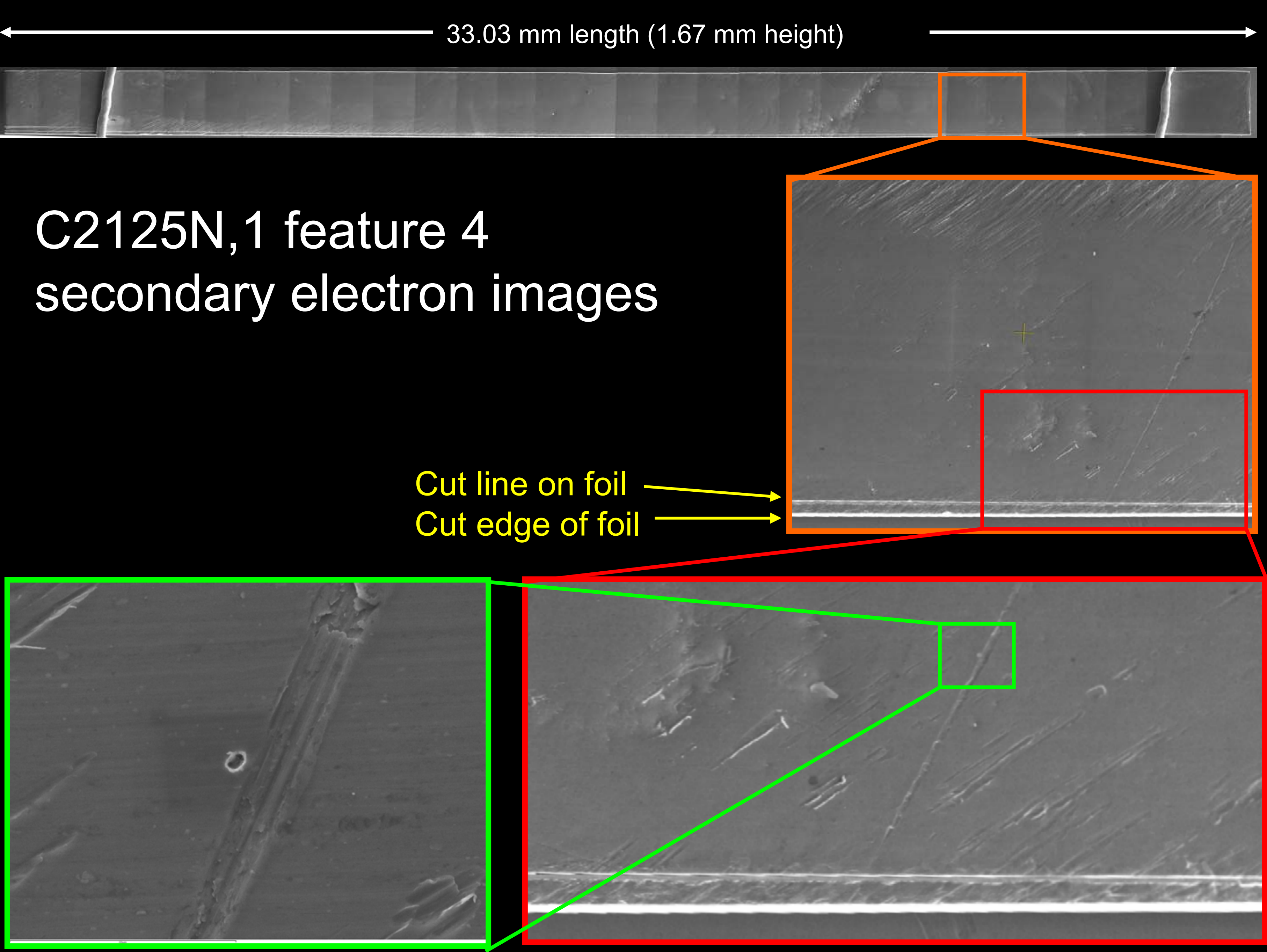
Oxygen, Magnesium, Silicon, Sulfur, Calcium (and probably also Iron) are seen above background levels



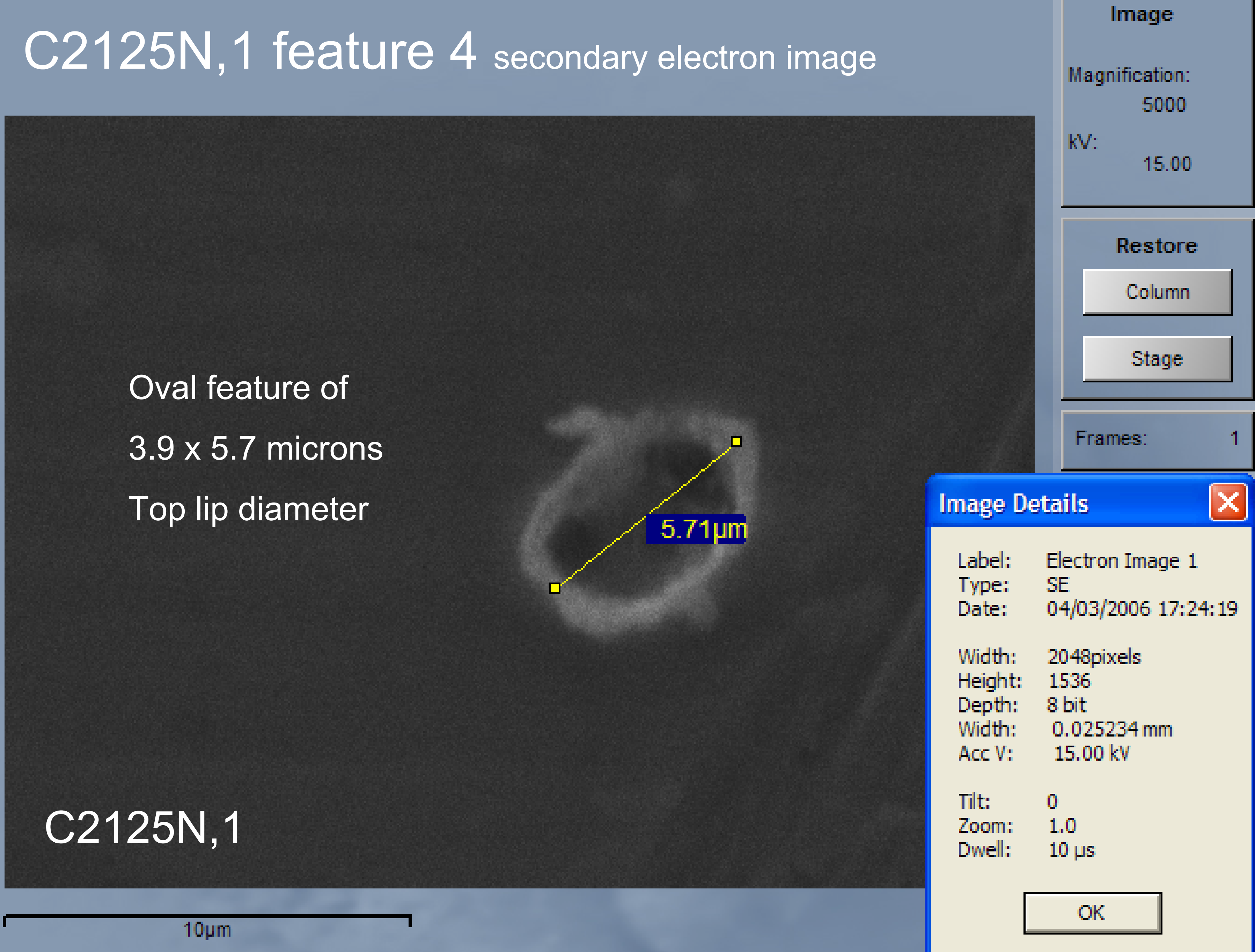


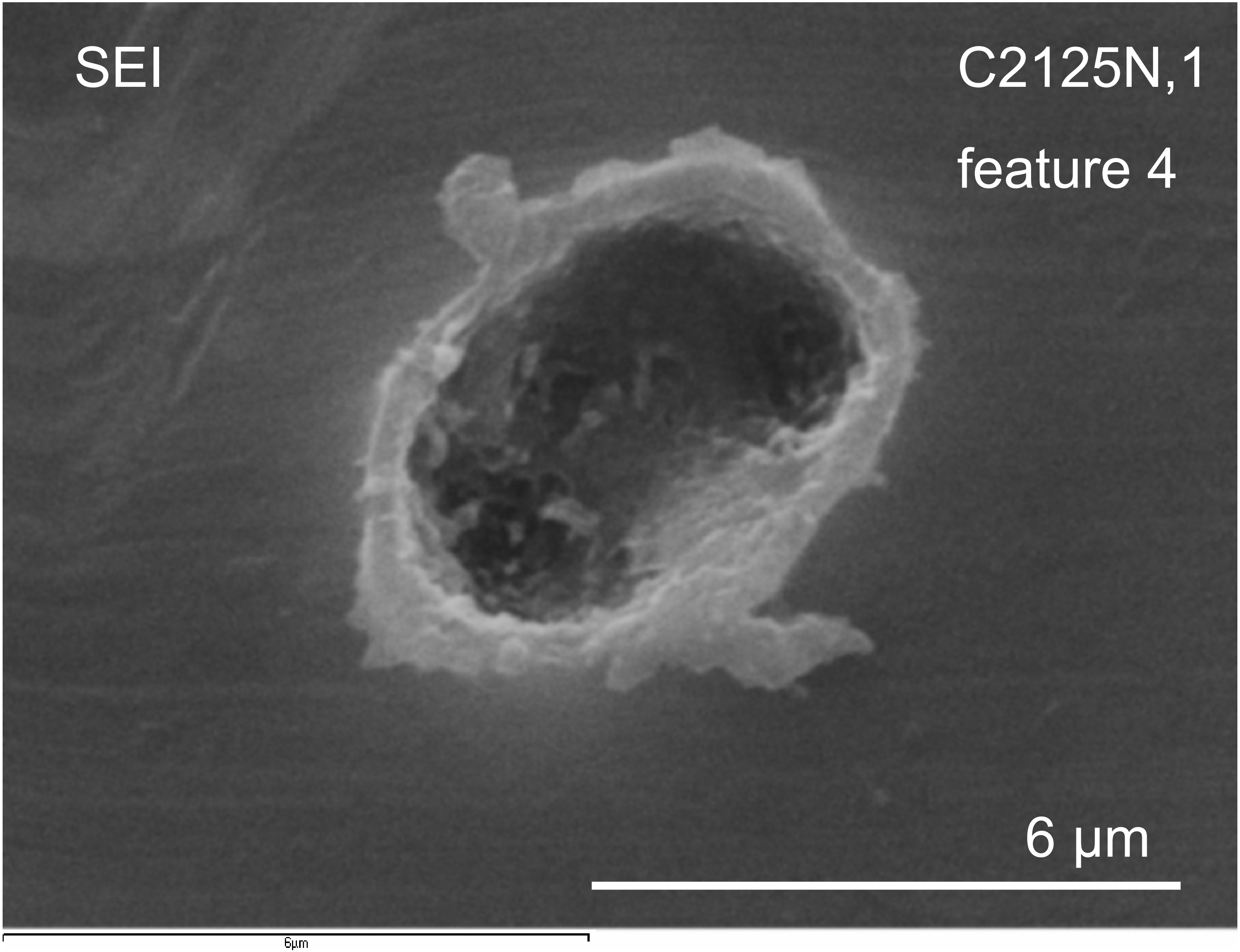
C2125N,1 feature 3

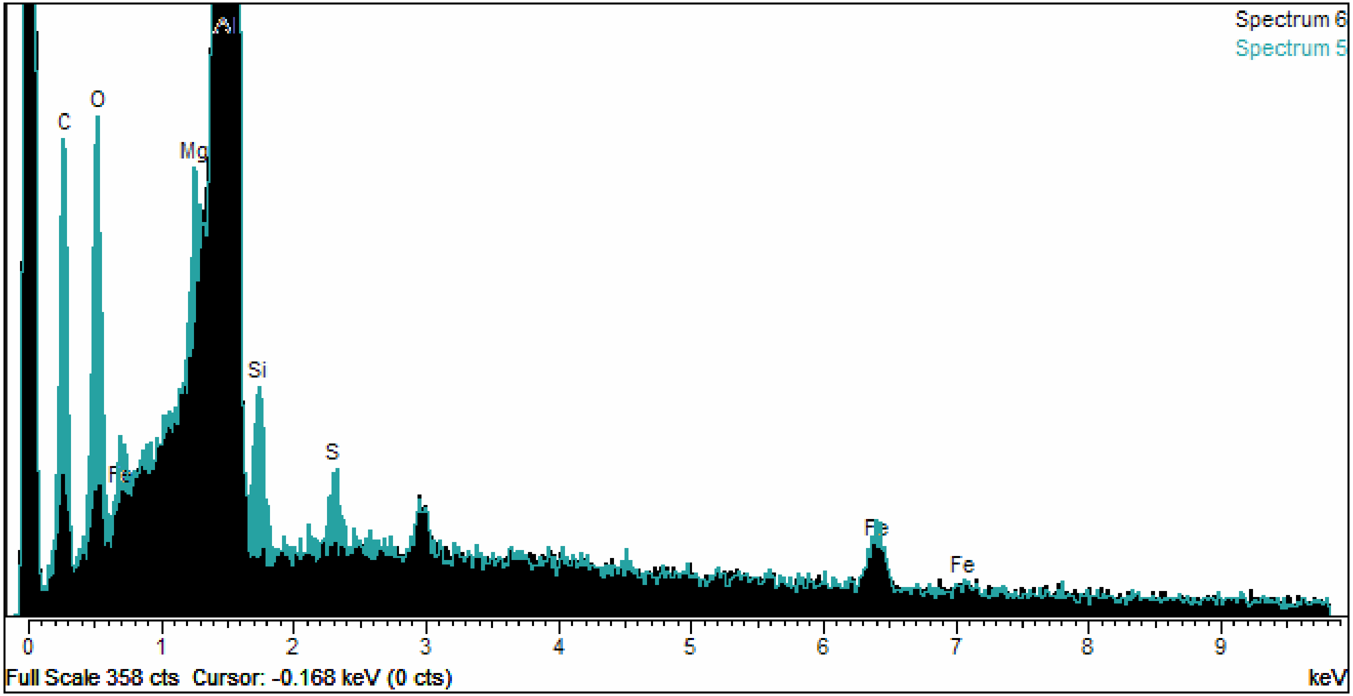
Element	Weight%	Weight% sigma	Atomic%	Compound%	Number of ions
Mg	21.37	0.68	19.05	35.43	7.83
Si	19.66	0.5	15.17	42.07	6.24
S	0.97	0.26	0.65	2.41	0.27
Ca	5.9	0.4	3.19	8.25	1.31
Cr	1.51	0.48	0.63	2.21	0.26
Fe	7.49	0.75	2.91	9.63	1.19
O	43.11	0.84	58.4		24


33.03 mm length (1.67 mm height)
C2125N,1 feature 4
secondary electron images
Cut line on foil
Cut edge of foil

C2125N,1 feature 4 secondary electron image




SEI
C2125N,1
feature 4
6 µm
6µm



C2125N,1

feature 4

Element	Weight%	Weight% sigma	Atomic%	Compound%	Formula	Number of ions
Mg	24.52	1.02	21.92	40.65	MgO	8.99
Si	15.25	0.62	11.8	32.63	SiO2	4.84
S	3.74	0.45	2.54	9.35	SO3	1.04
Ti	trace	0.6	bdl	Bdl	TiO2	trace
Fe	13.18	1.08	5.13	16.95	FeO	2.1
O	43.06	1.19	58.5			24

Conclusions

There are very few impact features on Stardust foil C2125N,1.

The foil surface shows complex topography.

In about 55 square millimetres surveyed at low magnification, only three impact features were found:

Walton feature 2: a sub-circular crater of 9.3 x 8.8 microns diameter, containing Mg and Fe silicate, Fe sulfide and ?organic residues

Walton feature 3: a circular crater of 2.4 microns, containing Mg, S, Ca and Fe silicate residue

Walton feature 4: an oval crater of 5.7 x 3.9 microns diameter with Mg and S bearing silicate residue.