Preliminary analysis of Stardust foils

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Foil surveys

- **Preliminary low resolution optical microscopy**
- **SEM surveys in secondary electrons**
  at moderate resolution (to detect all particles Dc >2 μm)
- **Higher resolution surveys under way**
- **EDX of identified impact sites**
- **Characterisation of possible contaminants**

Surveys completed:

Foil	Survey	Foil Area mm^2	Area scanned mm^2	Mag	Craters
C2125N (Walton)	1 (backscattered e-)	55	12.4	X1000	0*
	2 (secondary e^-)		34.6	X300	2
C2051N (Avebury)	1 (secondary e-)	49	49	X162	1
C2054N (Bletchley)	1 (secondary e-)	39	39	X185	8
C2060W (Calverton)	1 (secondary e-)	23	23	X135	2

***Potential craters seen in backscattered images are more clearly identified in secondary electrons. All surveys now in secondary e^-.**

C2125N Walton – scanning technique

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).

Survey 1: Automated backscattered electron (BSE) montage creation in flat, central area of foil at high magnification (x1000 mag, 126 μm 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).

Survey 2: Manual survey of overlapping secondary electron images (SEI) at x300 mag., 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 “Walton” imaged at OU at low mag., note tin wires.

C2125N Walton - Results from automated high resolution BSE survey.

No unambiguous impact features with Dc ≥ 5 µm found in 1500 frames of BSE automated montages from four campaigns 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 µm 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.

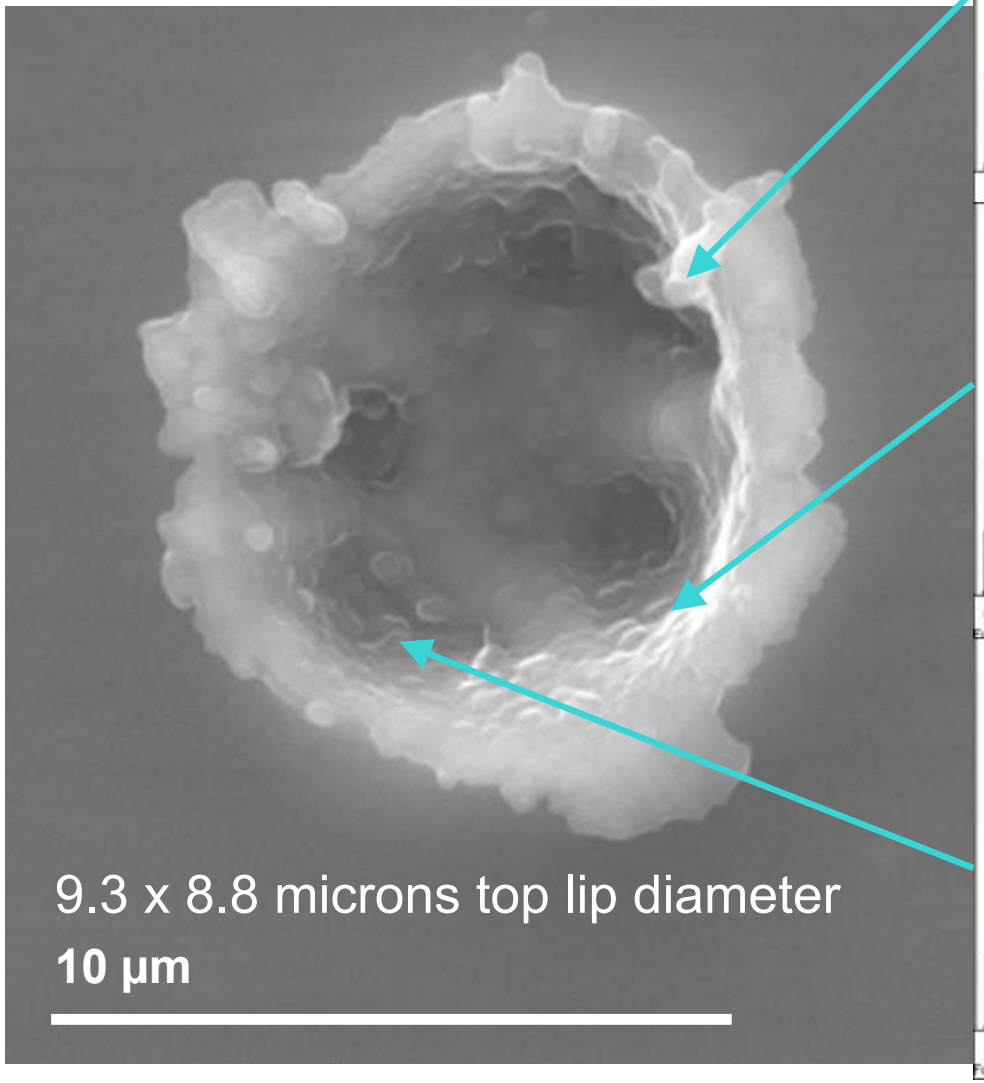
C2125N (Walton)

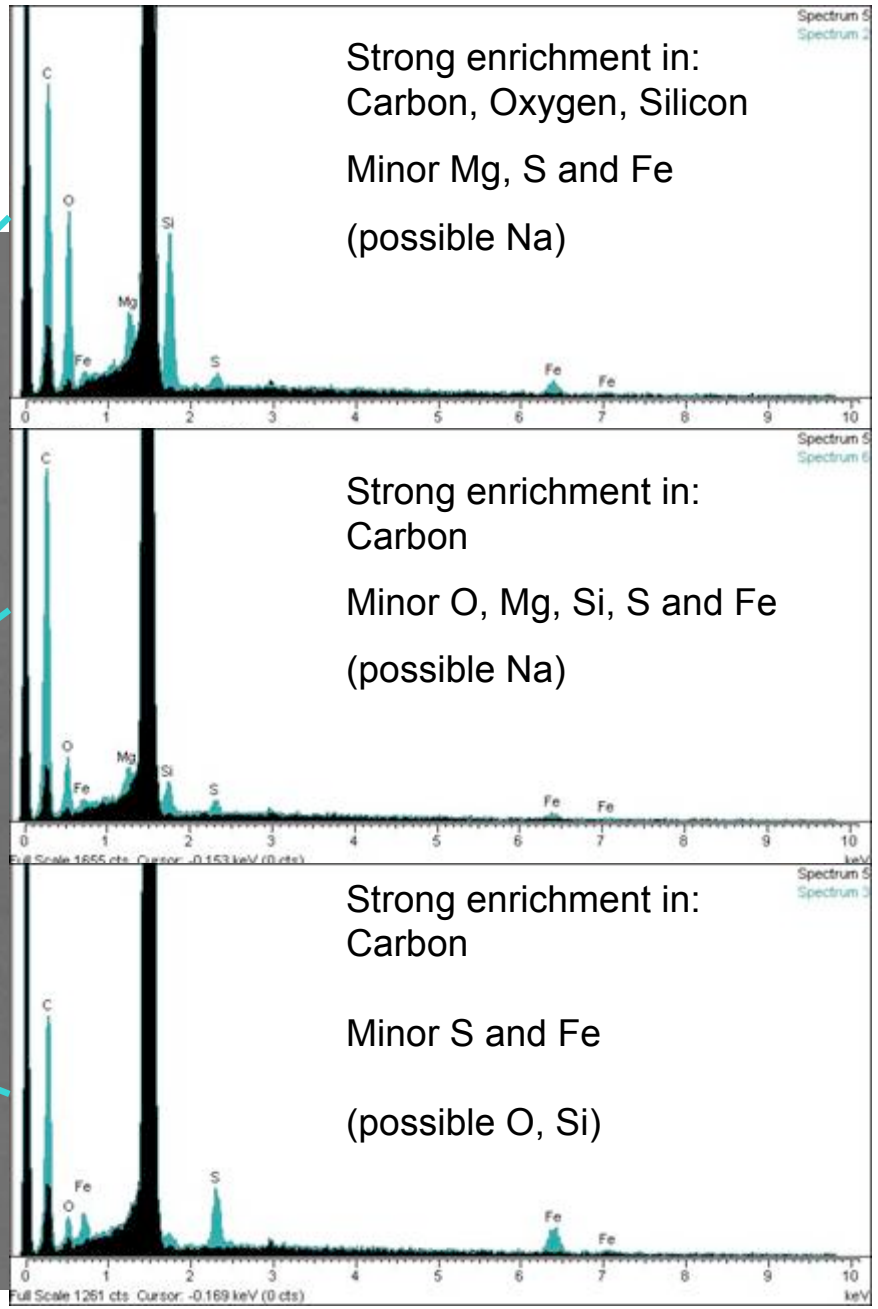
- **Total area of foil = 55 mm^2**
- **Area scanned 34.6 mm^2**
- **The foil surface shows complex topography with grooves and damage in at least 2 orientations plus aerogel ejecta.**

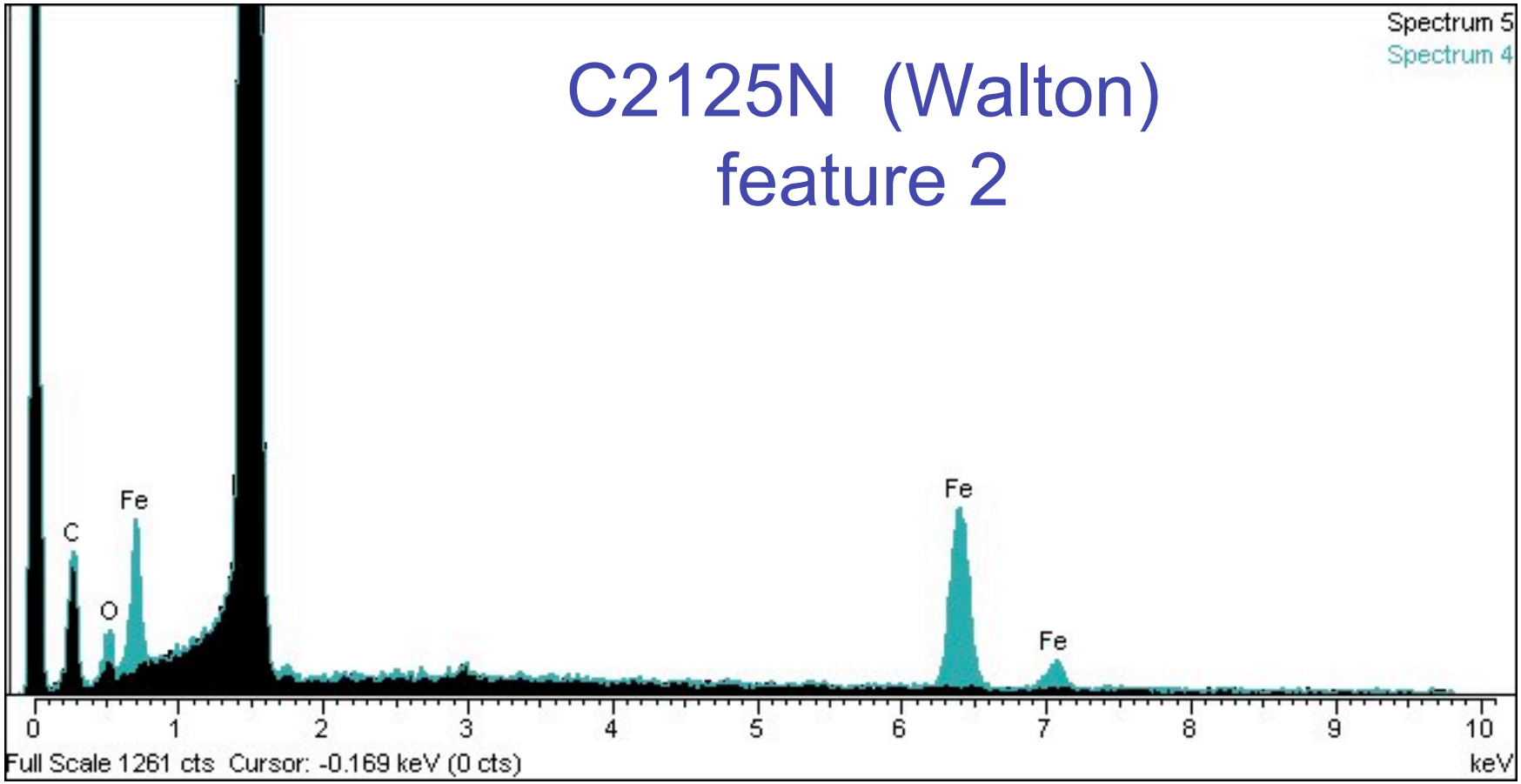
- **Craters found so far:**
  Walton feature 2: Sub-circular crater Dc = 9.3 x 8.8 µm
  Contains Mg and Fe silicate, Fe sulfide and ?organic residues
  Walton feature 3: Dc = 2.4 µm,
  Contains Mg, S, Ca and Fe silicate residue
  Walton feature 4: Oval crater Dc = 5.7 x 3.9 µm
  Residue yet to be analysed.

(NB only Feature 3 lay inside area of BSE survey)

C2125N (Walton) feature 2



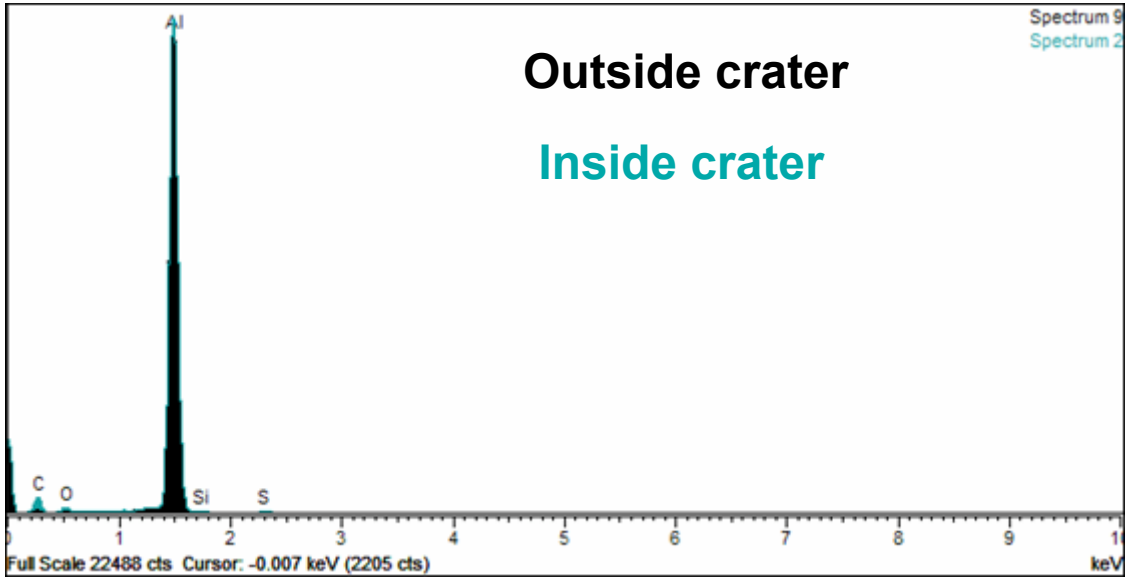


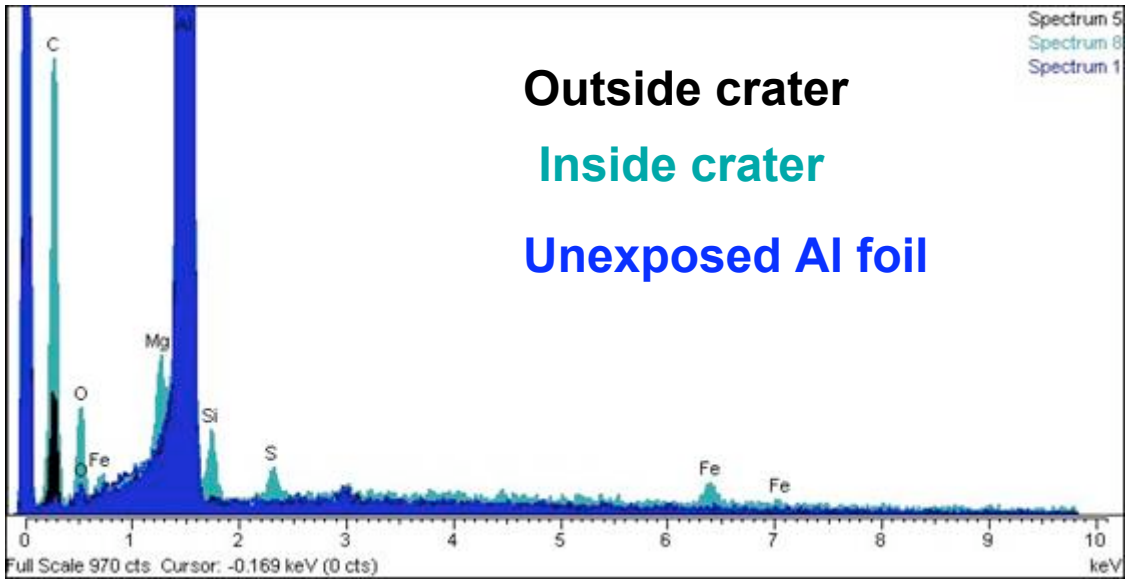


Fe-rich inclusion (shown in pale blue) in Aluminium alloy (black) shows no enrichment in Sulfur (as found in the impact feature 3), but minor Oxygen is present.

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.

Carbon really is in C2125N Walton feature 2

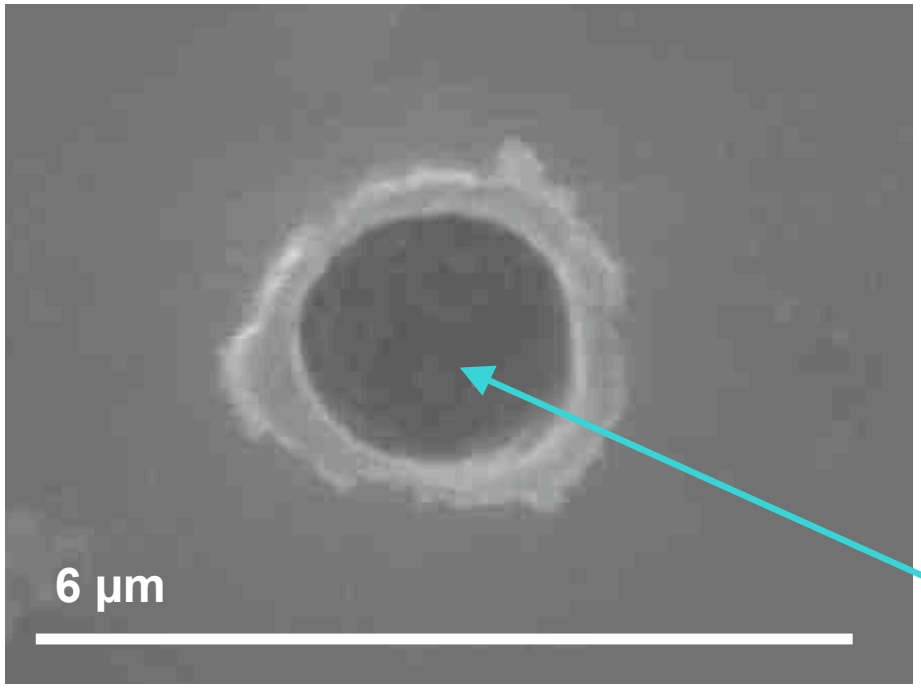




Comparison of spectra from map data taken inside and outside of the crater show an increase in carbon count rate, even in a full scale spectrum. This apparent excess cannot be explained by sample geometry alone.

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**).

Carbon levels inside the crater (shown in **pale blue**) are much higher.

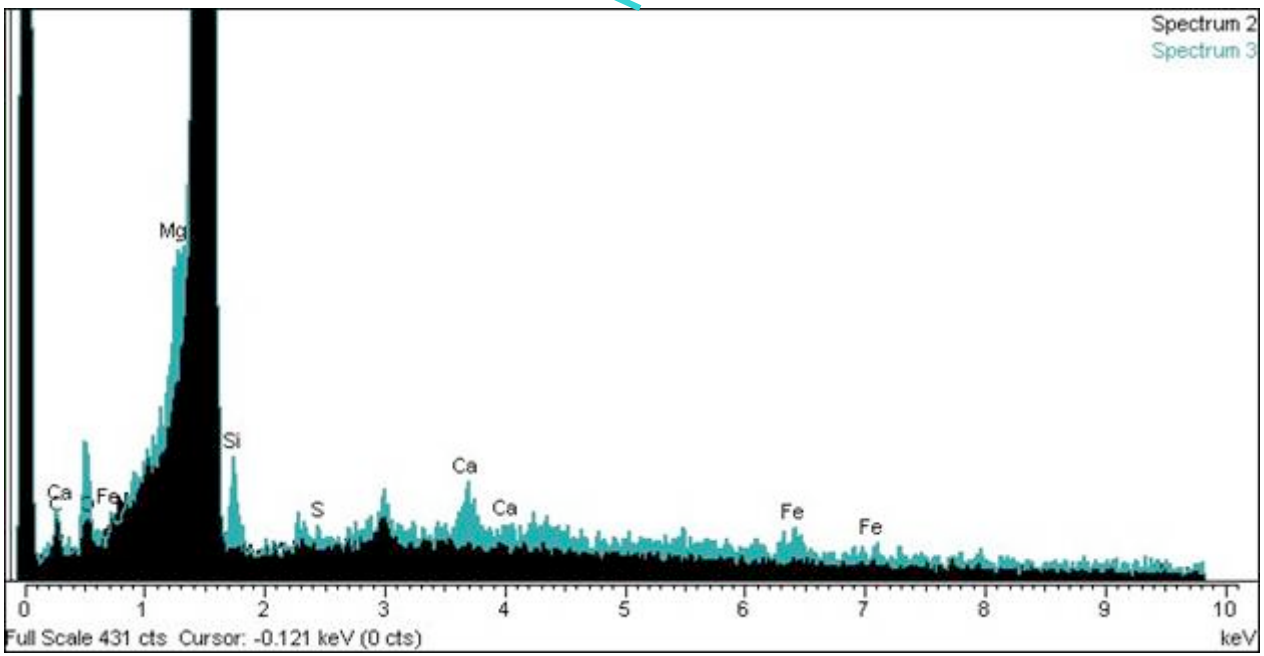


C2125N (Walton) feature 3

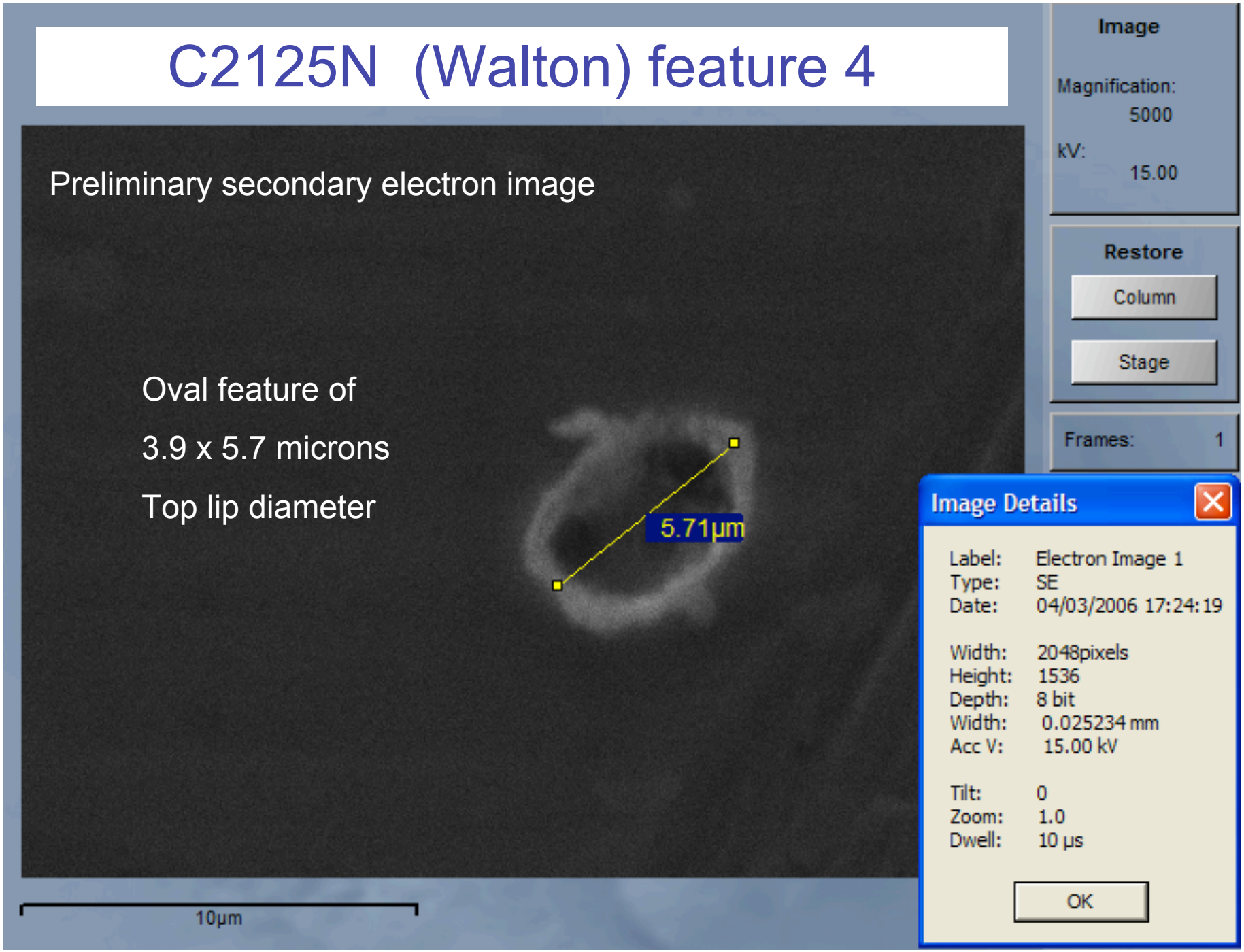
2.41 µm top lip diameter

Secondary electron image and energy dispersive X-ray spectrum

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



C2125N (Walton) feature 4



C2051N (Avebury)

- **Total area of foil = 49 mm^2**
- **About 10 % is covered by grooves and damage in at least 2 orientations: near-vertical and oblique**

- **Craters found so far:**

Crater 1: Dc = 6.7 µm. Clear lip, width up to 2 µm.
Initial studies indicate ~1µm width domains of residue containing Ca, Mg, Ti, (+Fe?). There is clearly more than one patch of residue within the crater.

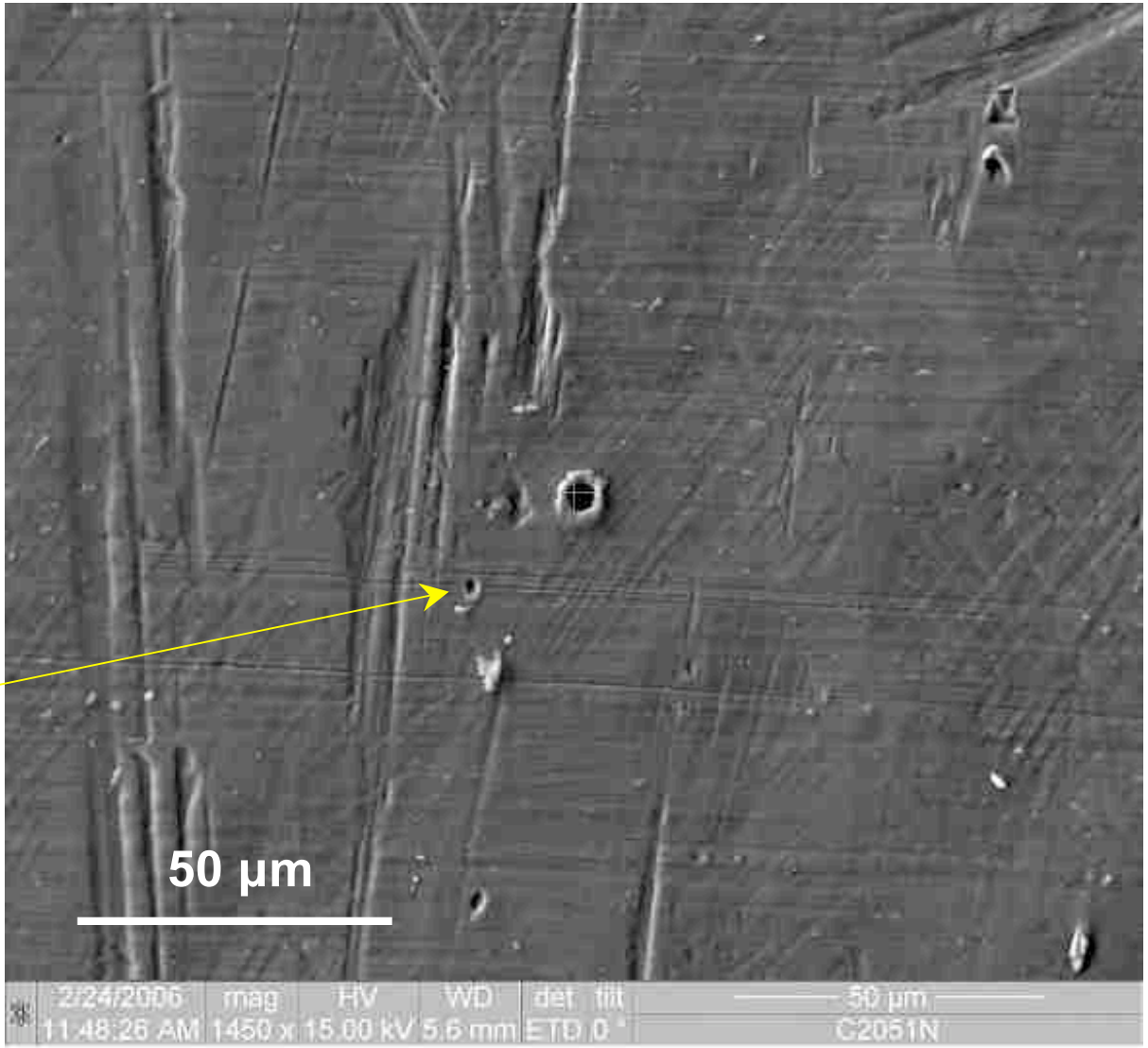
Potential Crater 1: Dc = 4.3 µm. No identified residue.

Potential Crater 2. Dc = 3.3 µm. In the same field of view as Crater 1
Not circular, no regular lip, no apparent residue.
Clearly overlays the oblique and horizontal grooves. Thus it may postdate the preparation of the foils and be extraterrestrial in origin.

Other pits are irregular in shape, have no easily identifiable lips and do not have any textural link to other craters or the foil damage.

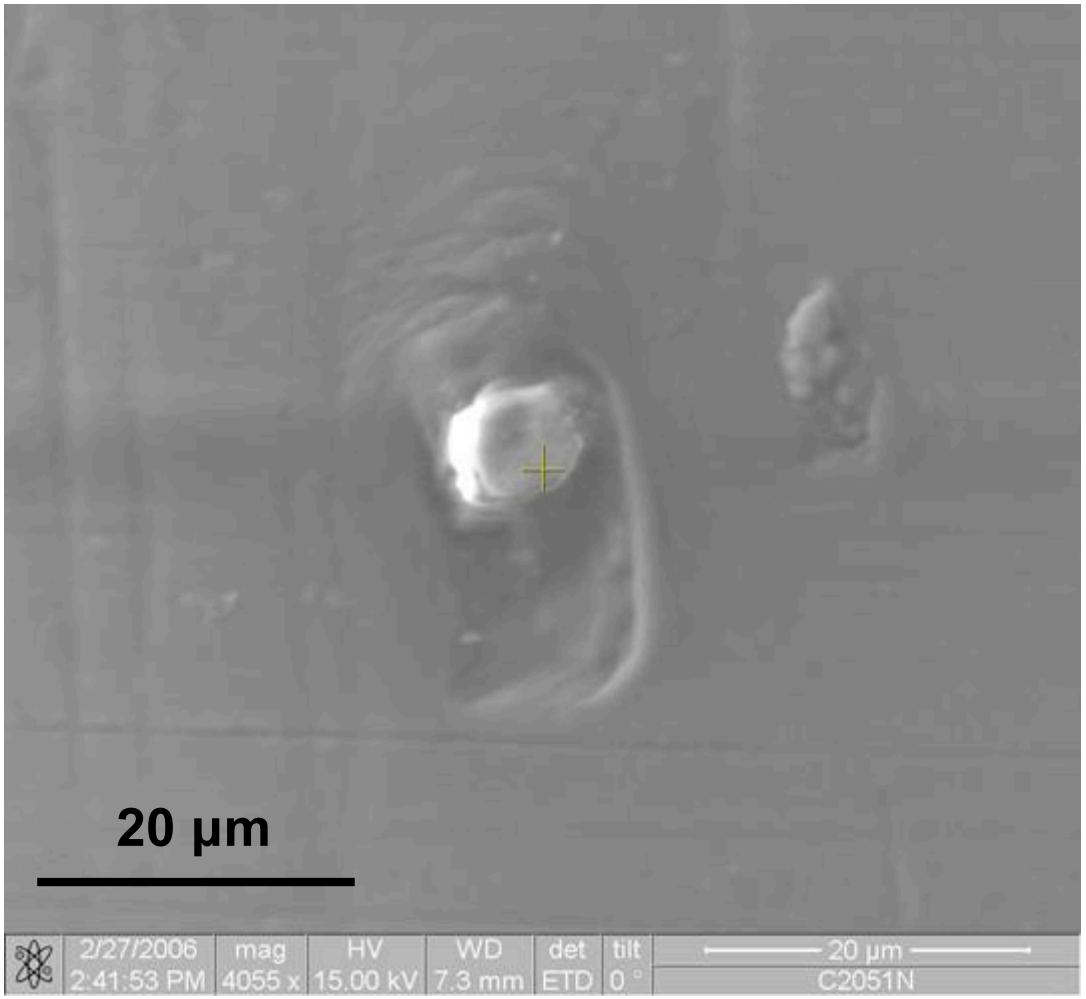
C2051N (Avebury) Crater 1 D_c=6.7 µm

- **Crater 1 clearly overlies and postdates the oblique fabric.**
- **Secondary Electron Image of Crater 1 in the centre of field overlies a pattern of grooves.**
- **(Potential Crater 2)**



C2051N (Avebury) Possible contamination

- **Grains of Ca-carbonate have been identified on the foil.**
- **Some appear to have been pressed into the foil.**
- **Other grains on the foil include traces of Na, S, Cl.**
- **Iron-rich patches are ubiquitous across the foil.**



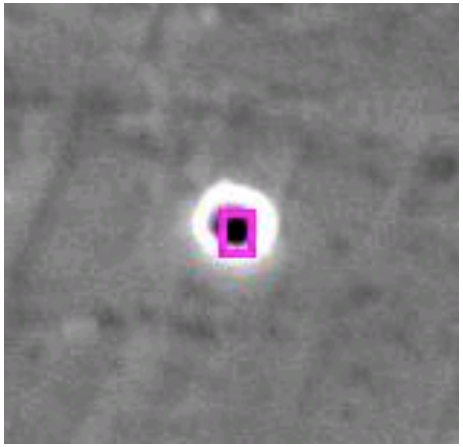
C2054N (Bletchley)

- **Total area of foil = 39 mm^2**
- **Less than 10% of this foil is covered by grooves and damage or aerogel.**

- **Craters found so far:**

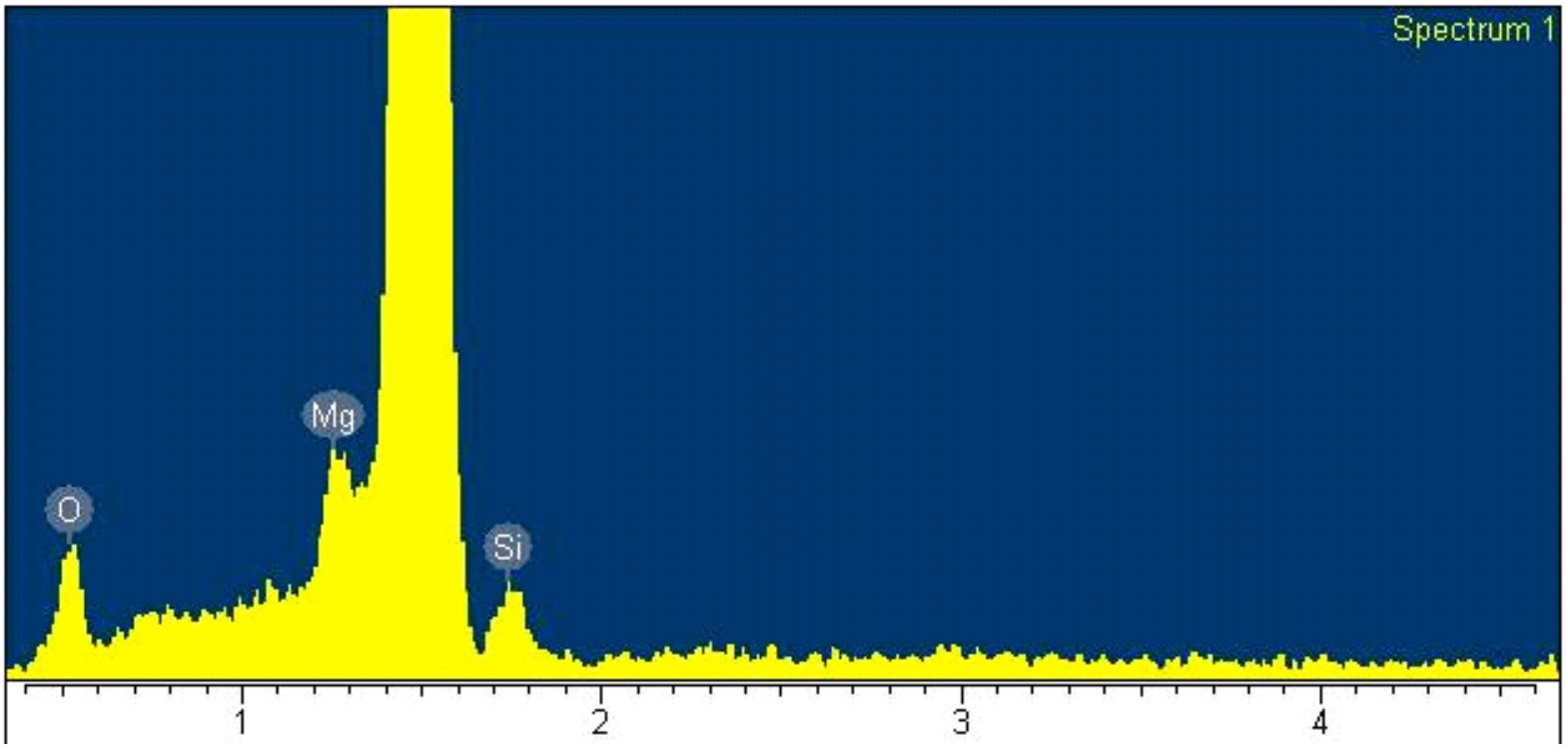
Crater 1 Dc = 12 µm. No residue detected.
Crater 2 Dc = 2 µm. Mg-Si residue detected.
Crater 3 Dc = 11.6 µm. (uncertain identification) No residue detected. No lip identified but is perfectly circular with rim.
Crater 4 Dc = 2.6 µm. Mg-Si (+Fe?) residue detected
Crater 5 Dc = 1.7 µm. No residue detected
Crater 6 Dc = 1.6 µm. Mg-Si residue detected
Crater 7 Dc = 1.3 µm. Trace of Si, no Mg or Fe detected.
Crater 8 Dc = 1.4 µm. Fe-Si detected, not clear whether this is contamination or genuine residue.
Crater 9 Dc = 1.7 µm. Mg, Si (+Fe?) residue

C2054N (Bletchley) crater 2

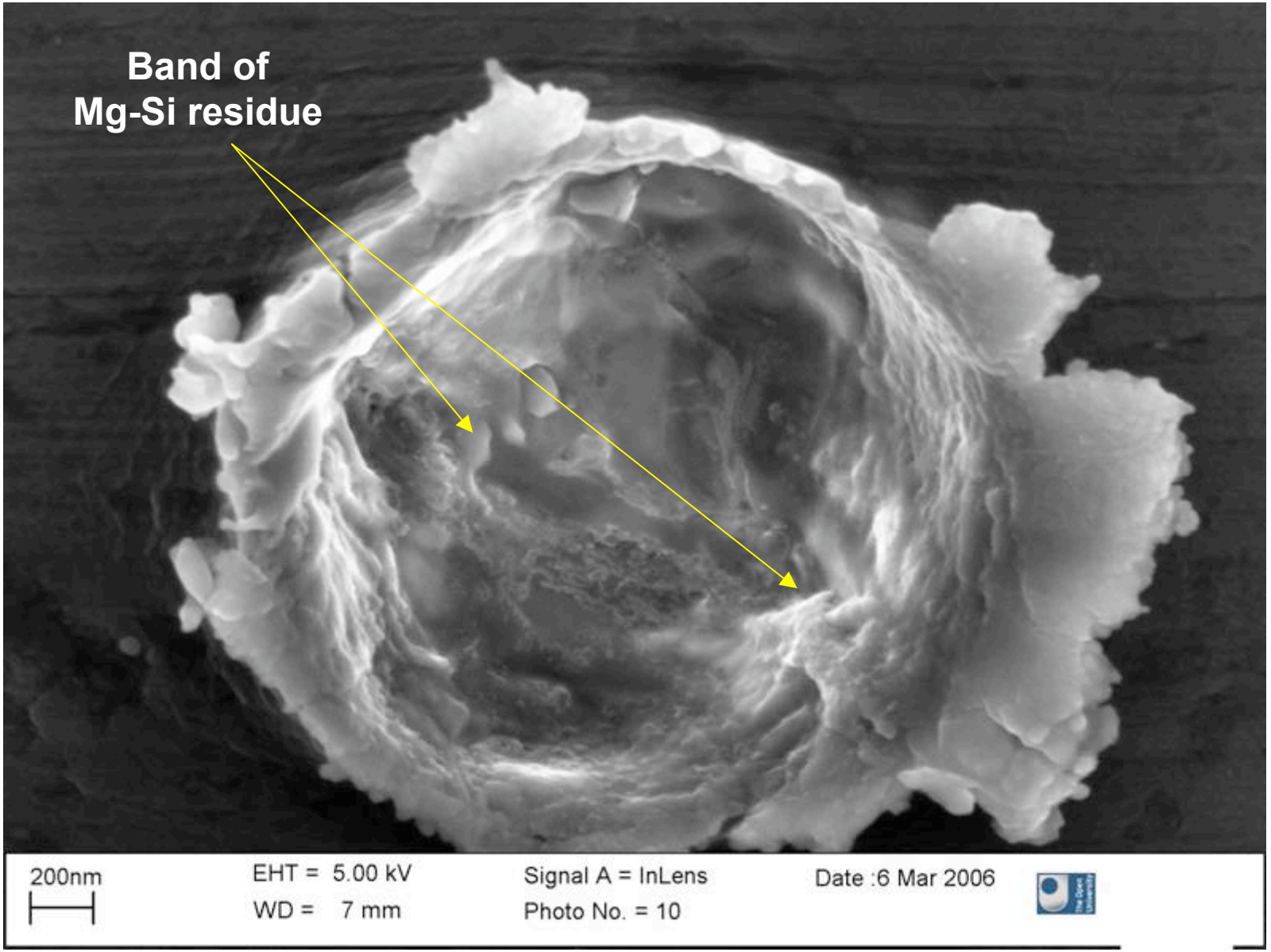


10 µm

Forsterite residue
Normalised data:
Mg:Si:O = 1.7 : 1 : 2.9



C2054N (Bletchley) crater 4



C2054N (Bletchley) Possible contamination

- **Contamination is similar to that of Avebury.**
- **Grains of Ca-carbonate have been identified on the foil.**
- **Some of these appear to have been pressed into the foil.**
- **Other grains on the foil include traces of Na, S, Cl and Zn.**
- **Iron-rich patches are ubiquitous across the foil.**
- **In addition to this, Fe-rich grains a few microns in diameter are present within pits. These grains appear to be part of the foils which were exposed by the milling process.**
- **Aerogel is present, with some lumps up to 200 mm width.**

C2060W (Calverton)

- **Total area of foil = 23 mm^2**
- **This foil has relatively minor damage although there is a noticeable horizontal grooving fabric.**

- **Craters found so far:**

Crater 1: Dc = 9 µm.

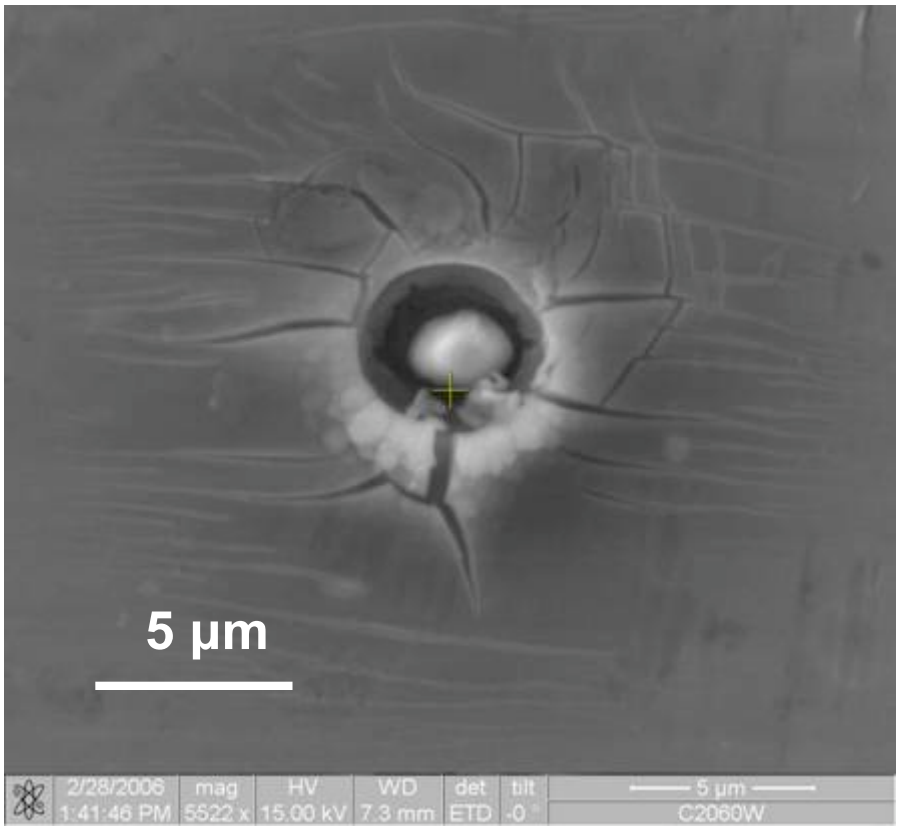
Mg and Mg, Si, S, Fe-bearing patches identified.
There appears to be more than 1 phase within the residue.
All analyses have Al from foil and possibly partially from the residues.

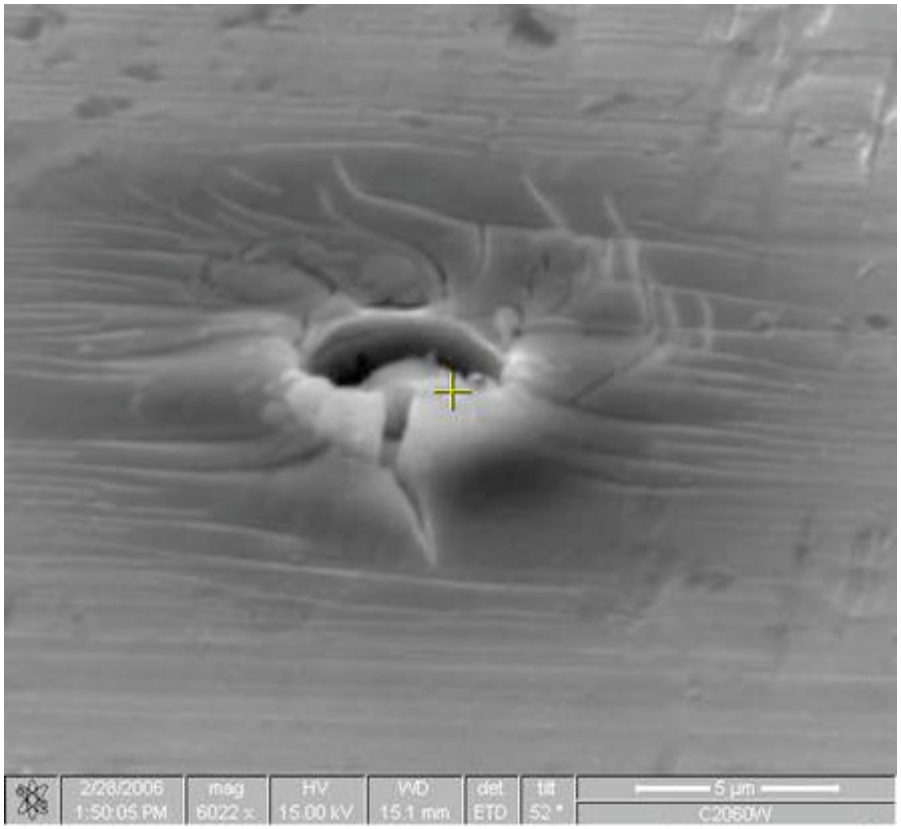
Crater 2: Dc = 4.4 µm.

(no clear ejecta pattern but is perfectly circular and bowl-shaped)
No residue detected.

C2060W (Calverton) Possible contamination

- **Iron-rich patches are ubiquitous across the foil.**
- **In addition Fe-rich grains a few microns in diameter are present within pits. They appear to be part of the foils which were exposed by the milling process.**





Sub-micron survey started

Dc = 360 nm crater on C2954N Bletchley.