

C2008N “Denbigh”

Stardust Cratering Subgroup Foil report. 28 June 2006

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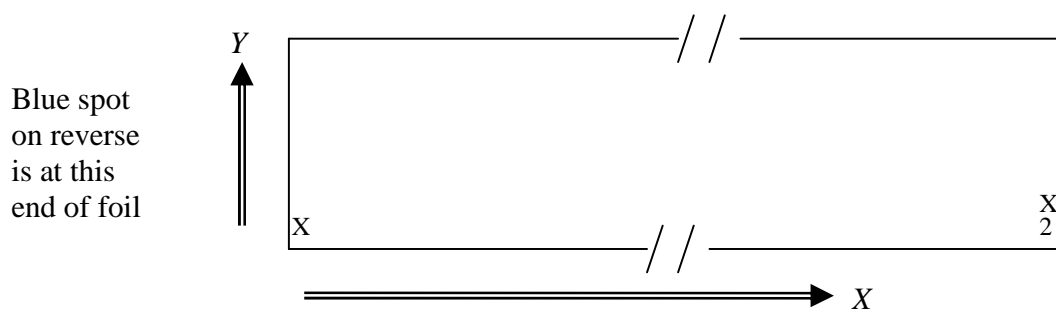
(1) General Information

General appearance: 32 x 1.5 mm.

Approximately 20% of the foil is covered by grooves and there is a scattering of aerogel across the foil.

Sample mounting: Held by two Sn-coated restraining wires on custom Al holder.

Foil Co-ordinates: Fiducial marks, size 5 μm , milled by ion beam foil near corners of long side:



All measured coordinates transformed to Coordinate system (X,Y) with origin at fiducial mark ‘X’ and X axis towards fiducial mark ‘X2’ Units of mm.

Crater surveys:

Quanta 200D Dual Beam FIB-SEM. Zeiss FEG SEM also used for some imaging with In-Lens images. D_c measurement accuracy checked with etched quartz graticule.

- Manual survey of entire foil (LOWRES): Secondary electrons 20 kV, 0.6 nA, x650 magnification. Nominal area 48 mm². Estimated complete to $D_c = 2\mu\text{m}$.
- Automated surveys of smaller areas (1 mm² and 4 mm²). 20 kV, 0.6 nA, x1000 magnification, secondary electrons, 2048 x 1792 pixel resolution, Kalman frame (3) averaging. Working distance 7 mm. Resolution limited by flatness of foil over sub-area.

Resolution limited by flatness of foil over sub-area.

SA1: Nominal 4 mm². Actual area 4.30 mm². Estimated complete to $D_c = 1.2\mu\text{m}$.

Corners (4.44, 0.11) (4.44, 1.17) (8.48, 1.17) (8.48, 0.11).

SA2: Nominal 1 mm². Actual area 1.09 mm². Estimated complete to $D_c = 0.8\mu\text{m}$.

Corners (3.33, 1.20) (4.38, 1.21) (3.34, 0.17) (4.39, 0.18).

- Dense cluster around (2.46, 0.11): 15 kV, 0.5nA, secondary electrons, x9000 magnification. Area 390 μm^2 . Estimated complete to $D_c = 200\text{nm}$.

EDX measurements:

15 KV, 75 s acquisition time, 1-10 analyses per crater. Crater analysed were 610 nm to 14.5 μm diameter. The main qualitative dataset in Section 5 below was taken at 0⁰ stage tilt.

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(2) Crater Location

LOWRES manual survey of entire foil.

Target completeness limit $D_c=5\mu\text{m}$. Estimated complete to $D_c=2\mu\text{m}$.

Craters 2, 2a and 2b are the largest members of a compact cluster.

Coordinates reproducible to $\sim 0.1\text{mm}$ due to flexure of foil.

Total number of craters = 153

LOWRES survey
87 craters

| Crater | X (mm) | Y (mm) | Dc (μm) |
|--------|-----------|-----------|-------------------------|
| 1 | 1.16 | 1.33 | 1.9 |
| 2 | 2.46 | 0.11 | 2.6 |
| 2a | | | 1.6 |
| 2b | | | 1.0 |
| 3 | 2.66 | 1.02 | 3.5 |
| 4a | 2.80 | 0.21 | 1.5 |
| 4b | 2.80 | 0.21 | 1.6 |
| 5 | 2.80 | 0.25 | 1.2 |
| 6 | 3.36 | 0.33 | 4.1 |
| 7 | 3.74 | 1.04 | 4.0 |
| 8 | 4.10 | -0.02 | 2.4 |
| 9 | 4.89 | 1.17 | 2.4 |
| 10 | 5.44 | 0.30 | 1.8 |
| 11 | 6.04 | 0.48 | 1.6 |
| 12 | 6.17 | 0.54 | 1.6 |
| 13 | 6.78 | 1.46 | 14.5 |
| 14 | 7.52 | 0.08 | 2.2 |
| 15 | 8.09 | 0.64 | 1.5 |
| 16 | 8.42 | 0.96 | 2.2 |
| 17 | 8.62 | 1.48 | 1.1 |
| 18 | 8.64 | 0.94 | 1.8 |
| 19 | 9.31 | 0.82 | 2.6 |
| 20 | 10.24 | 1.25 | 2.4 |
| 21 | 10.18 | 0.25 | 3.7 |
| 22 | 10.35 | 0.03 | 1.5 |
| 23 | 10.82 | 0.58 | 1.2 |
| 24 | 11.19 | 0.84 | 2.8 |

| | | | |
|----|-------|------|-----|
| 25 | 11.25 | 0.59 | 1.4 |
| 26 | 11.40 | 0.26 | 2.0 |
| 27 | 11.75 | 0.77 | 1.6 |
| 28 | 11.81 | 0.76 | 1.8 |
| 29 | 12.03 | 0.96 | 2.3 |
| 30 | 12.91 | 1.26 | 1.5 |
| 31 | 13.06 | 1.30 | 1.2 |
| 32 | 13.12 | 0.95 | 1.1 |
| 33 | 13.15 | 0.97 | 1.1 |
| 34 | 13.16 | 0.43 | 1.4 |
| 35 | 13.47 | 0.88 | 1.1 |
| 36 | 14.70 | 0.28 | 1.3 |
| 37 | 15.11 | 0.29 | 2.3 |
| 38 | 15.06 | 0.41 | 3.3 |
| 39 | 15.75 | 0.90 | 1.2 |
| 40 | 15.76 | 0.73 | 1.4 |
| 41 | 15.77 | 0.20 | 1.9 |
| 42 | 15.99 | 0.54 | 2.0 |
| 43 | 15.94 | 1.30 | 3.8 |
| 44 | 16.09 | 1.16 | 1.2 |
| 45 | 16.00 | 0.54 | 2.1 |
| 46 | 18.10 | 0.57 | 1.0 |
| 47 | 18.26 | 1.00 | 2.1 |
| 48 | 18.93 | 0.53 | 2.1 |
| 49 | 18.88 | 1.10 | 1.8 |
| 50 | 18.90 | 1.46 | 1.3 |
| 51 | 19.08 | 1.22 | 0.9 |
| 52 | 19.57 | 0.43 | 1.6 |
| 53 | 19.75 | 0.35 | 2.9 |
| 54 | 19.75 | 0.35 | 0.7 |
| 55 | 22.12 | 0.73 | 4.7 |
| 56 | 22.11 | 0.69 | 1.9 |

| | | | |
|----|-------|-------|-----|
| 57 | 22.28 | 0.01 | 1.6 |
| 58 | 23.46 | 1.51 | 2.2 |
| 59 | 23.74 | 0.17 | 2.2 |
| 60 | 23.71 | 0.91 | 4.4 |
| 61 | 24.33 | 1.14 | 1.3 |
| 62 | 24.54 | 1.36 | 2.2 |
| 63 | 24.53 | 0.61 | 1.8 |
| 64 | 24.63 | 0.45 | 2.9 |
| 65 | 24.54 | 1.36 | 2.1 |
| 66 | 24.70 | 1.31 | 1.2 |
| 67 | 24.63 | 0.45 | 3.1 |
| 68 | 24.60 | 0.28 | 2.3 |
| 69 | 24.76 | 0.81 | 1.4 |
| 70 | 24.74 | 0.87 | 1.0 |
| 71 | 24.74 | 0.88 | 0.6 |
| 72 | 25.20 | 0.44 | 1.2 |
| 73 | 27.46 | 1.23 | 1.4 |
| 74 | 27.62 | 0.96 | 1.8 |
| 75 | 28.61 | 1.10 | 1.8 |
| 76 | 28.78 | 1.18 | 1.1 |
| 77 | 28.73 | 0.85 | 1.6 |
| 78 | 28.99 | -0.05 | 1.3 |
| 79 | 29.94 | 0.75 | 2.8 |
| 80 | 31.42 | 1.46 | 1.3 |
| 81 | 32.02 | 0.85 | 1.5 |
| 82 | 12.80 | 0.97 | 0.7 |
| 83 | 5.30 | 0.56 | 2.6 |
| 84 | 7.68 | 0.26 | 2.2 |

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(2) Crater Location (continued)

Randomly selected areas SA1 and SA2 to obtain completeness to $D_c \sim 1 \mu\text{m}$.

Selected area containing compact cluster. Complete to $D_c \sim 200 \text{ nm}$.

Craters that also appear in LOWRES survey are cross-referenced.

Area SA1
27 craters

| Crater | X (mm) | Y (mm) | D_c (μm) |
|----------|-----------|-----------|----------------------------|
| 101 = 16 | 8.44 | 0.90 | 2.2 |
| 102 | 8.30 | 0.80 | 1.3 |
| 103 | 8.24 | 0.83 | 1.4 |
| 104 = 15 | 8.10 | 0.60 | 1.5 |
| 105 | 7.85 | 0.96 | 1.3 |
| 106 = 84 | 7.70 | 0.24 | 2.2 |
| 107 | 7.47 | 0.50 | 1.4 |
| 108 | 7.44 | 0.93 | 1.5 |
| 109 | 7.09 | 0.68 | 1.2 |
| 110 | 6.52 | 1.14 | 1.2 |
| 111 = 12 | 6.19 | 0.58 | 1.7 |
| 112 | 6.24 | 1.05 | 0.95 |
| 113 = 11 | 6.04 | 0.50 | 1.6 |
| 114 | 5.54 | 0.41 | 1.2 |
| 115 = 10 | 5.44 | 0.35 | 1.6 |
| 116 | 5.32 | 0.52 | 1.1 |
| 117 = 83 | 5.32 | 0.64 | 2.6 |
| 118 | 5.24 | 0.72 | 1.3 |
| 119 | 5.20 | 0.89 | 1 |
| 120 | 4.78 | 0.67 | 1.6 |
| 121 | 4.51 | 0.48 | 1 |
| 122 | 4.53 | 0.78 | 1 |
| 123 | 4.54 | 0.94 | 0.72 |
| 124 | 4.52 | 0.94 | 0.74 |
| 125 | 4.50 | 0.95 | 0.63 |
| 126 | 4.50 | 1.08 | 0.51 |
| 127 | 4.53 | 1.13 | 1.5 |

Area SA2
13 craters

| Crater | X (mm) | Y (mm) | D_c (μm) |
|---------|-----------|-----------|----------------------------|
| 128 | 4.21 | 1.15 | 0.8 |
| 129 | 3.91 | 1.18 | 1.3 |
| 130 = 7 | 3.69 | 1.06 | 3.6 |
| 131 | 3.81 | 0.87 | 0.9 |
| 132 | 3.46 | 0.96 | 0.9 |
| 133 | 4.14 | 0.72 | 0.7 |
| 134 | 3.71 | 0.66 | 1.2 |
| 135 | 3.65 | 0.64 | 0.8 |
| 136 | 4.05 | 0.60 | 0.7 |
| 137 | 4.20 | 0.51 | 1.8 |
| 138 = 6 | 3.35 | 0.30 | 3.7 |
| 139 | 4.32 | 0.24 | 0.8 |
| 140 | 3.43 | 0.26 | 0.9 |

Cluster
38 craters

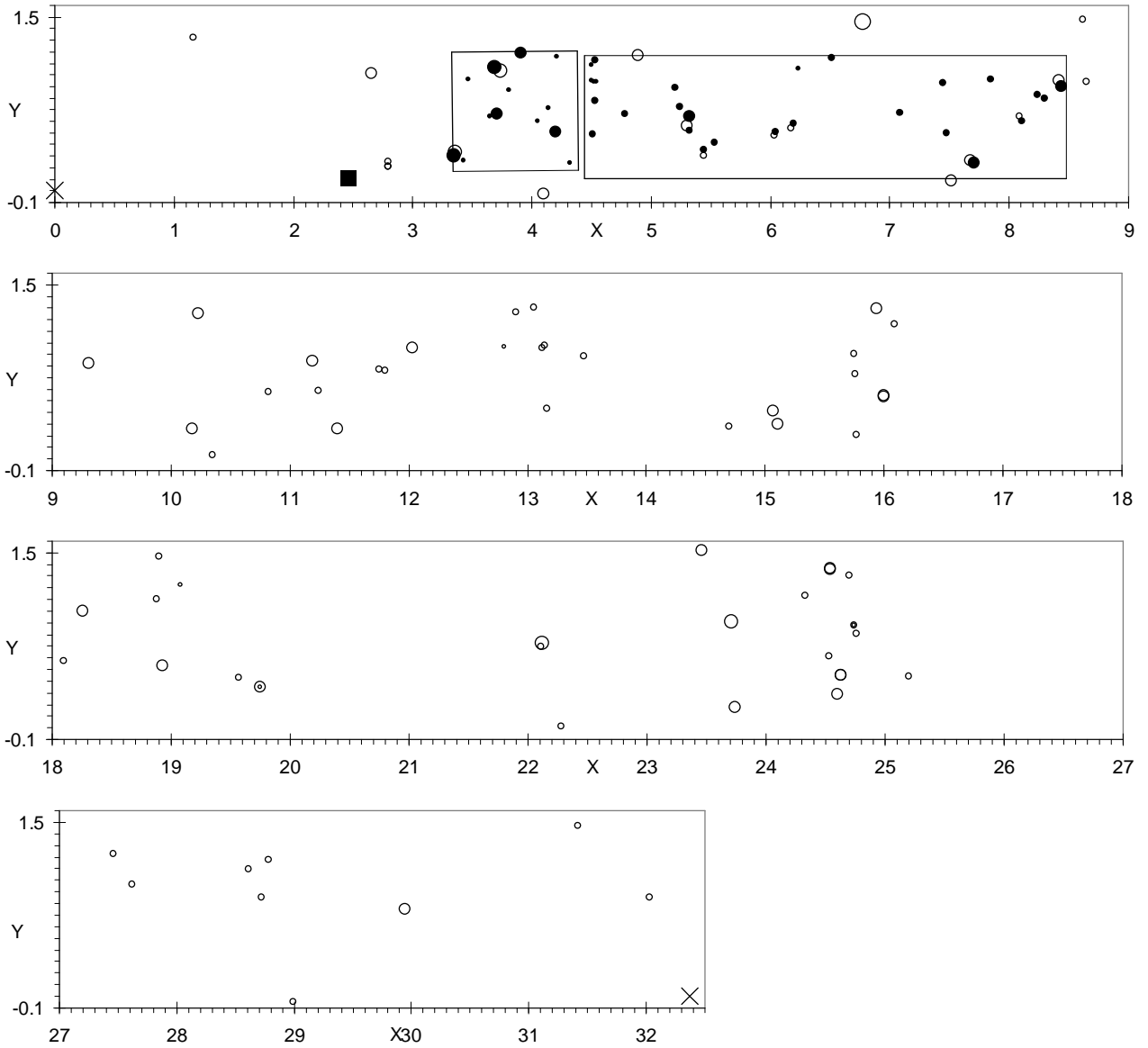
| Crater | X (mm) | Y (mm) | D_c (μm) |
|--------|-----------|-----------|----------------------------|
| 2 | 2.46 | 0.11 | 2.6 |
| 2a | | | 1.6 |
| 2b | | | 1 |
| 2c | | | 0.75 |
| 2d | | | 0.52 |
| 2e | | | 0.49 |
| 2f | | | 0.42 |
| 2g | | | 0.42 |
| 2h | | | 0.39 |
| 2i | | | 0.36 |
| 2j | | | 0.35 |
| 2k | | | 0.35 |
| 2l | | | 0.33 |
| 2m | | | 0.31 |
| 2n | | | 0.3 |
| 2o | | | 0.29 |
| 2p | | | 0.28 |
| 2q | | | 0.28 |
| 2r | | | 0.26 |
| 2s | | | 0.22 |
| 2t | | | 0.2 |
| 2u | | | 0.19 |
| 2v | | | 0.18 |
| 2w | | | 0.18 |
| 2x | | | 0.18 |
| 2y | | | 0.18 |
| 2z | | | 0.17 |
| 2aa | | | 0.15 |
| 2ab | | | 0.15 |
| 2ac | | | 0.15 |
| 2ad | | | 0.15 |
| 2ae | | | 0.15 |
| 2af | | | 0.13 |
| 2ag | | | 0.13 |
| 2ah | | | 0.13 |
| 2ai | | | 0.13 |
| 2aj | | | 0.13 |
| 2ak | | | 0.12 |

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(2) Crater Location (continued)

X indicates fiducial marks

Open circles are LOWRES survey craters, filled circles are sample area craters, solid square is cluster.



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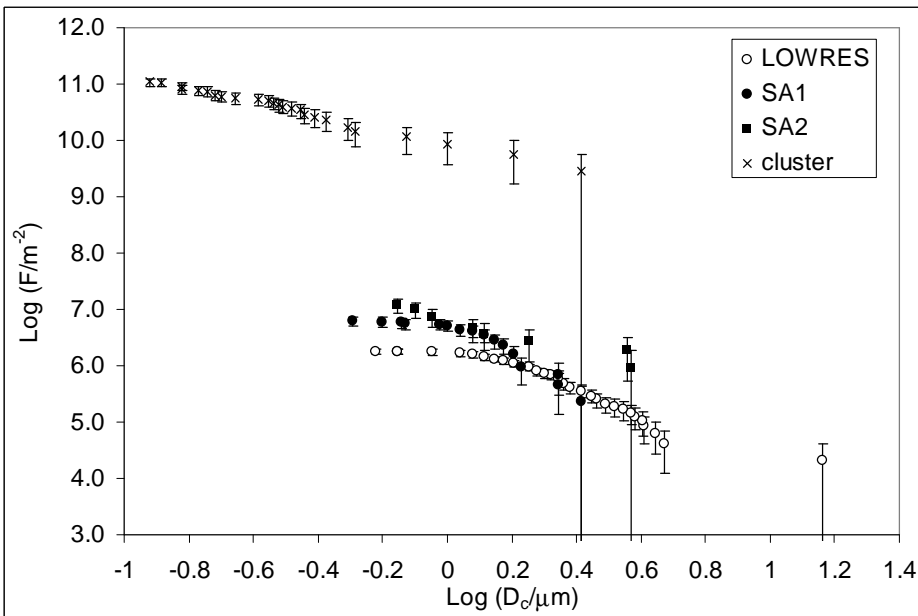
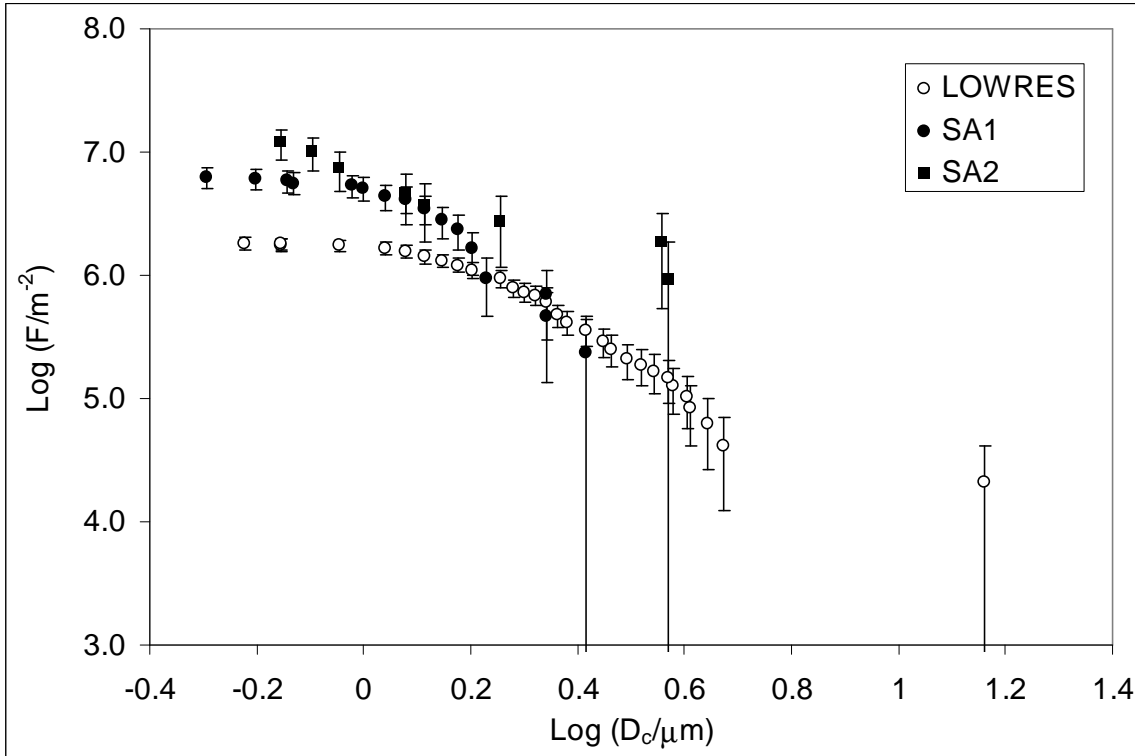
(3) Size distribution

Crater sizes are listed in crater location tables.

Size distributions plotted separately for each area scanned due to differing completeness limits.

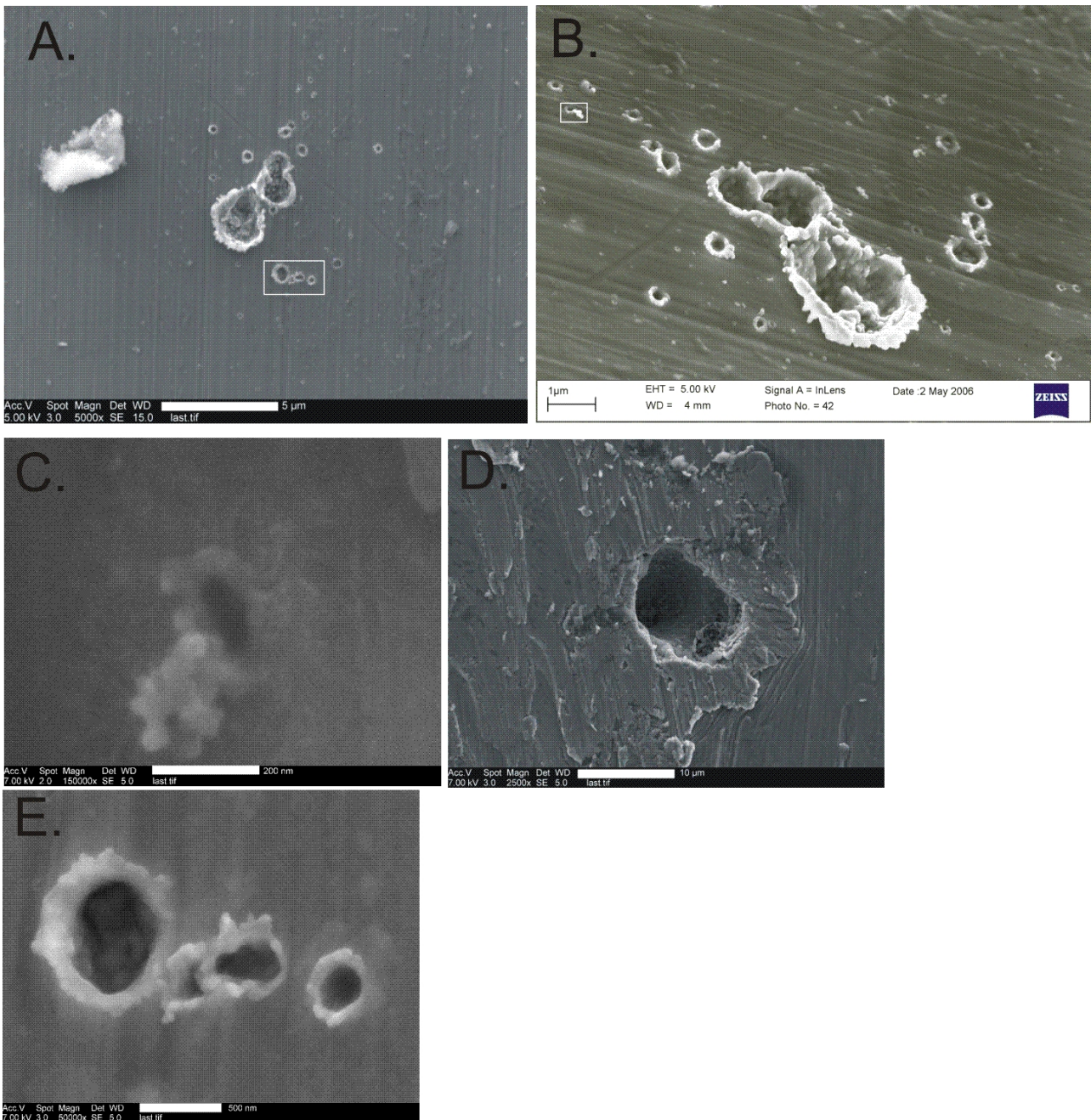
Crater distributions appear non-random on scales of a few mm

Error bars reflect counting statistics only.



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(4) Crater Images



A. Crater Cluster. Scale bar 5 μm . ETD image. B. Crater cluster in oblique view (In Lens Image). Scale bar 1 μm . C. Example of smaller crater (seen within square of B, top left corner). Scale bar 200 nm. Secondary Electron image. D. Largest crater on foil ($D_c = 14.5 \mu\text{m}$). This crater has been damaged. Secondary Electron image. Scale bar 10 μm . E. Craters within rectangle on A. Scale bar 500 nm. Secondary electron image.

Ejecta rims are present in the smallest craters but the rims tend to be more irregular (e.g. C) than the larger craters.

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(5) Composition

The craters identified in the LOWRES survey were reanalysed for residue composition (Table of EDS analyses below) and groupings identified are summarised in Table of Summary Qualitative EDS Analyses. Residue was detected in almost all of the craters in this size range. The relationship between crater size and residue is being explored and will be documented in a separate report. Smaller craters e.g. < 610 nm either did not show residue possibly because of insufficient X-ray counts or because of the difficulty of satisfactory image resolution under the conditions suitable for X-ray analyses. About 20% of the craters have Fe-S or Fe-Ni-S; 34% Mg-Fe silicate and 24% a mixture of those two groupings. The cluster of 38 craters was found to have residue compositions indistinguishable from the main crater population and is included within this dataset.

Contamination within the craters includes Cl-bearing phases and Fe-rich grains exposed from within the foil. Carbon contamination is present in the form of carbonate on the outer surface of the foil; carbon contamination may also be present on the rims of some of the craters where C-enrichments were found e.g. Crater 13. Mo is another trace contaminant.

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(5) Composition (continued)

Table of Crater Residue Composition in C2008N

| Crater | Elements | Dc (μm) | Crater | Elements | Dc (μm) | Crater | Elements | Dc (μm) |
|--------------------|-----------------------------------|-------------------------|--------|----------------------|-------------------------|--------|---|-------------------------|
| 1 | Si | 1.9 | 28 | Fe, Si | 1.8 | 56 | Fe, S | 1.9 |
| 2 (38 cluster) | | 0.12 to 2.6 | 29 | Fe, Si | 2.3 | 57 | Na, (Cl) | 1.6 |
| 3 | Mg, Fe, Si + FeS? | 3.5 | 30 | Mg, Si | 1.5 | 58 | Trace Fe | 2.2 |
| 4a | Mg-Fe Si | 1.5 | 31 | Fe, Si | 1.2 | 59 | FeS | 2.2 |
| 4b | Mg, Fe, Si | 1.6 | 32 | Mg, Si, S, Fe | 1.1 | 60 | Ca, Fe, Si | 4.4 |
| 5 | Mg, Si | 1.2 | 33 | Fe, S, Si | 1.1 | 61 | Fe, S | 1.3 |
| 6 | Ca-rich, Mg, Si | 4.1 | 34 | Fe | 1.4 | 62 | Cl, K, Na, S, Si, Fe, F | 2.2 |
| 7 | Na-rich, Mg-Fe silicate, (+S) | 4 | 35 | Fe, Si and Mg, Si | 1.1 | 63 | Cr, Fe, S, Si | 1.8 |
| 8 | Fe, S | 2.4 | 36 | Fe, S, Si, (Mo) | 1.3 | 64 | Fe, Mg, Si, S | 2.9 |
| 9 | Mg, Fe, Si +Fe, S | 2.4 | 37 | Fe, Si, S, Mg | 2.3 | 65 | Fe, S, C; (Ca, C, K, S, Na, Cl contam on side?) | 2.1 |
| 10 | Mg, Si, Fe | 1.8 | 38 | Fe, Mg, Si; S | 3.3 | 66 | Fe, Mg, Si, S | 1.2 |
| 11 | Si (no Fe) | 1.6 | 39 | Fe, S, Si | 1.2 | 67 | Mg, Fe, Si | 3.1 |
| 12 | Fe, S | 1.6 | 40 | Fe, S, Si | 1.4 | 68 | Mg, Fe, Si | 2.3 |
| 13 | C, Mg, Fe, S, Si, Ca | 14.5 | 41 | Mg, Si | 1.9 | 69 | Fe, S | 1.4 |
| 14 | Mg, Si, Fe | 2.2 | 42 | Mg, Si, Fe, S | 2 | 70 | Fe, S | 1 |
| 15 | Fe, S | 1.5 | 43 | K, Na, Mg, Fe, Si, S | 3.8 | 71 | Fe | 0.61 |
| 16 | Mg, Si, Fe, S (+ Fe, S) grains | 2.2 | 44 | Fe, S | 1.2 | 72 | Mg, Si | 1.2 |
| 17 | Fe, S | 1.1 | 45 | Mg, Si | 2.1 | 73 | Fe, S | 1.4 |
| 18 | Fe, S | 1.8 | 46 | Mg, Si, S, Fe | 1 | 74 | Fe, S | 1.8 |
| 19 | Mg, Si, Fe, S | 2.6 | 47 | Mg, Si, Fe, S | 2.1 | 75 | Fe, S, Mg, Si | 1.8 |
| 20 | Na, Si | 2.4 | 48 | Mg, Fe, Si | 2.1 | 76 | Fe, Si | 1.1 |
| 21 | Mg, Si, Ca, Fe | 3.7 | 49 | Mg, Si, Fe, S | 1.8 | 77 | Fe, S, Mg, Si | 1.6 |
| 22 | Fe, S | 1.5 | 50 | Fe, S, Si | 1.3 | 78 | Not analysed | 1.3 |
| 23 | Mg, Si, S, Fe | 1.2 | 51 | Fe (S) no O | 0.89 | 79 | Fe, S, Si | 2.8 |
| 24 | Si, Fe, S, Mg, Mo, | 2.8 | 52 | Mg, Si | 1.6 | 80 | Not analysed | 1.3 |
| 25 | Mg, Fe, Si | 1.4 | 53 | Ca, Si, Mg, Fe | 2.9 | 81 | Ca, Fe | 1.5 |
| 26 | Fe, Ni, S | 2 | 54 | Trace Fe | 0.73 | 82 | Fe, S | 0.68 |
| 27 | Fe, Si | 1.6 | 55 | Mg, Fe, Si, O | 4.7 | | | |

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(5) Composition (continued)

Summary of Qualitative EDS Analyses of Crater Residue (D_c 610 nm to 14.5 μ m):

| Residue | Frequency | % |
|------------------------------|-----------|------|
| Fe S | 18 | 18.9 |
| Fe Ni S | 2 | 2.1 |
| Cr-bearing | 1 | 1.1 |
| Mg Fe silicate | 32 | 33.7 |
| silicate + sulphide | 23 | 24.2 |
| Ca silicate (Mg Fe) | 7 | 7.4 |
| K, Na silicates (+sulphide) | 3 | 3.2 |
| Cl, Fe-bearing contamination | 3 | 3.2 |
| None/trace Si or Fe | 6 | 6.3 |
| Total | 95 | 100 |

Figure 1. Qualitative EDS Analyses of Crater Residue in C2008N

