National Aeronautics and
Space Administration

Orion EFT-1 Post-Flight Inspection and Analysis

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in support of NASA JSC/Jacobs JETS
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Acknowledgements

- Hypervelocity Impact Tech. Group (HVIT)
  - Dr. Eric Christiansen
- Jacobs JSC Engineering and Technical Support Team
  - James Hyde
  - Bruce Alan Davis
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  - Dr. Eve Berger
- Lockheed Martin Space Systems Company
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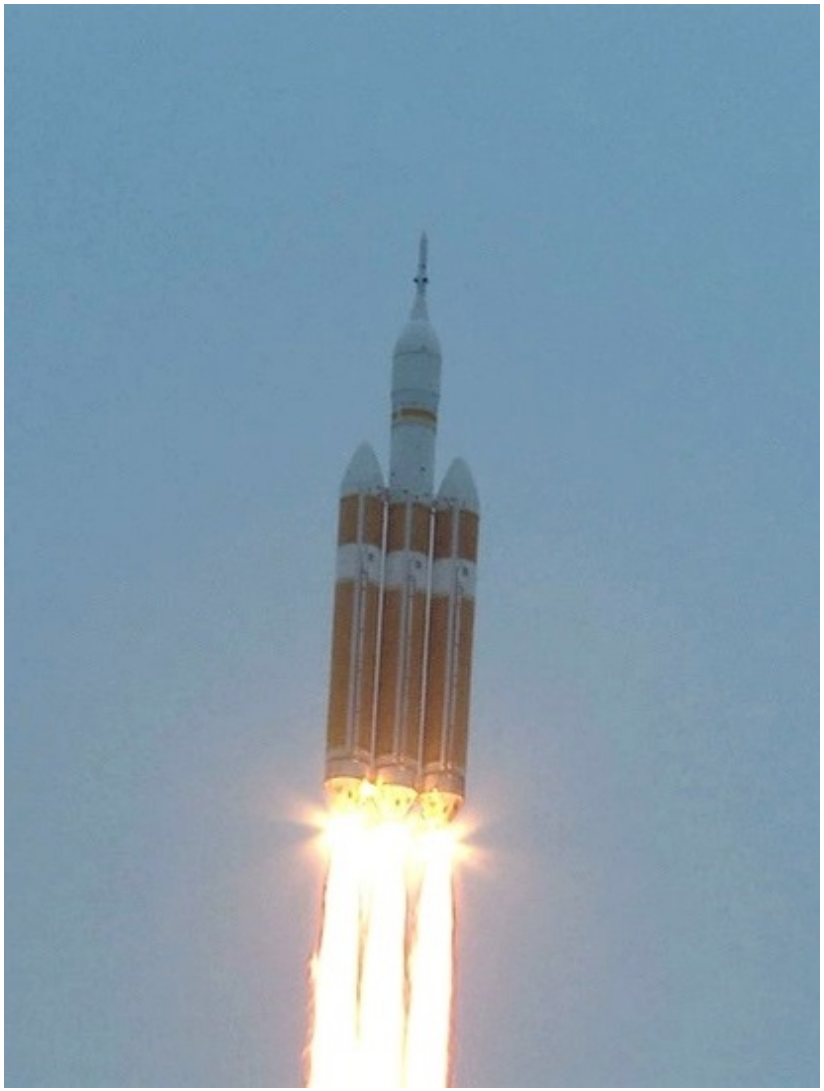
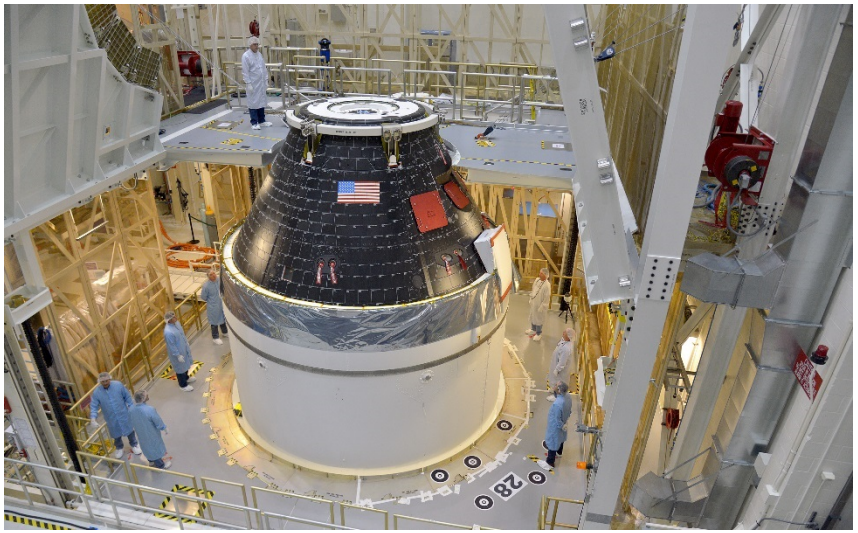
  - Kevin Deighton
- JSC-Remote Hypervelocity Test Laboratory

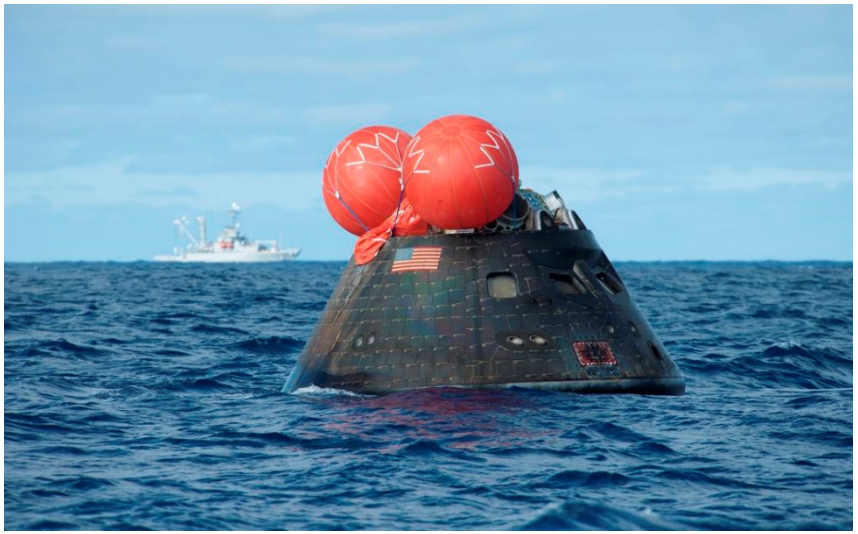
Detailed inspection of the unique Orion EFT-1 mission has identified six candidate solid particle impacts

- Orion's ascent fairing, backshell and landing recovery system design provide a nearly pristine return surface of in-flight solid particle impacts
- Orion's EFT-1 mission profile took the vehicle into some of the highest density debris bands surrounding the Earth beyond where most returned surfaces have ventured
  - Pre-flight preparatory ground based testing demonstrated the anticipated crater characteristics for particles in the sub-millimeter size range
  - Pre- and post-flight visual inspections identified six candidate impact craters with characteristic dimensions in the millimeter range
  - CT scans revealed crater characteristics and depths point to impact particles in the submillimeter size range
- On-going analysis efforts are focused on identifying the material and impact characteristics that generated the identified craters
  - Scanning electron microscope and spectrum measurements are looking for traces of the remnants of the embedded impactor
  - Hydrodynamic simulations consider impact speed, obliquity and shape effects

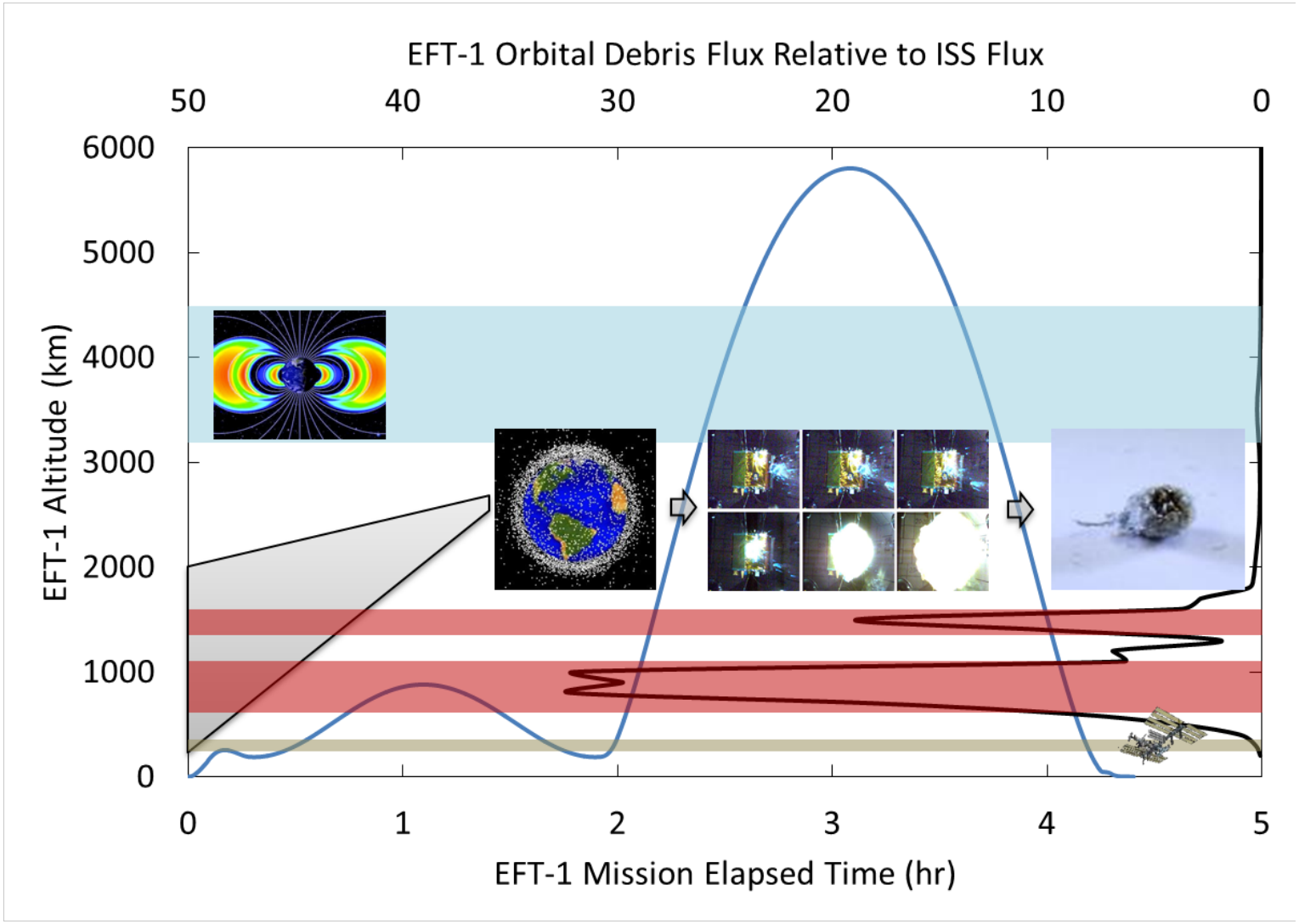
Orion's crew module uses a shrouded, ceramic tile that does not significantly ablate on atmospheric reentry







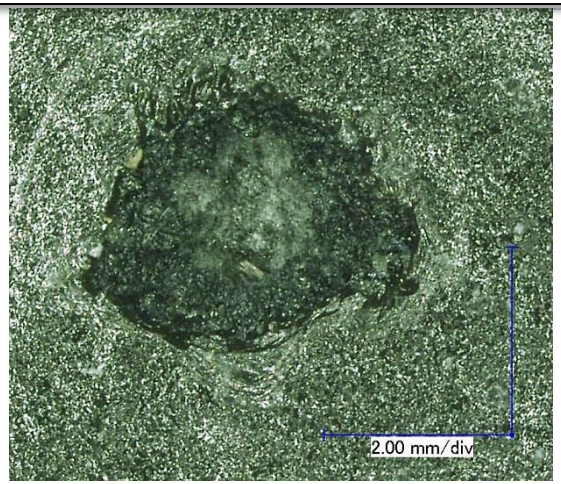
Orion's EFT-1 flight profile was planned to visit Earth's highest debris bands multiple times in the brief flight

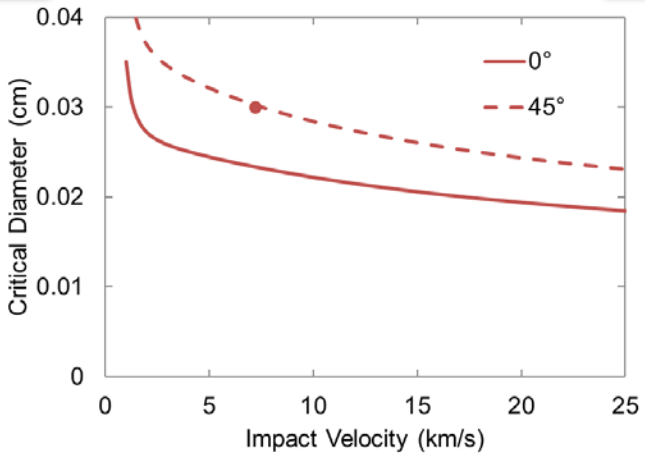


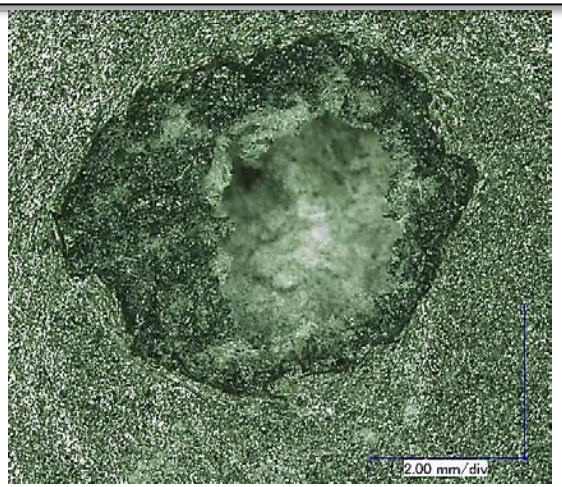
Preparatory tests performed to identify crater characteristics from sub-millimeter impacting particles

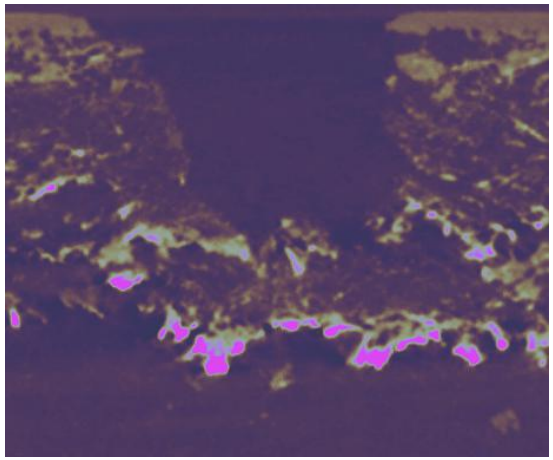
0.3 mm Al @ 7.13 km/s & 45°
Feature Size = 6.0 x 5.9 mm
Depth = 2.3 mm

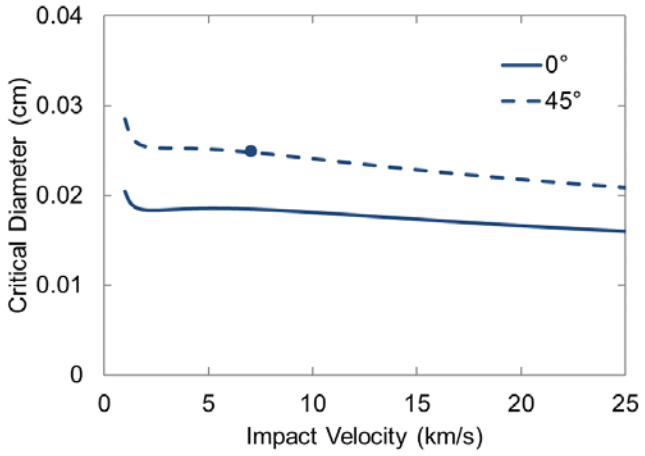
0.25 mm SS @ 6.97 km/s & 45°
Feature Size = 4.7 x 5.5 mm
Depth = 3.8 mm

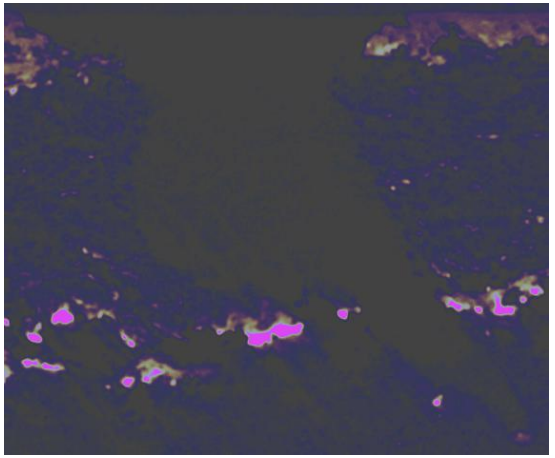










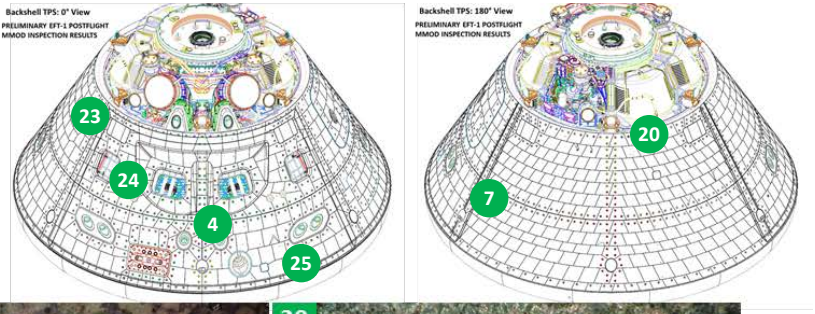


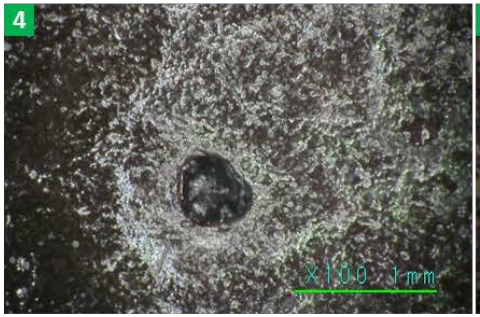
Inspections of the crew module took place in four phases from pre-flight to detailed post-flight inspections

The detailed pre- and post-flight inspections identified six craters with millimeter range characteristic dimensions

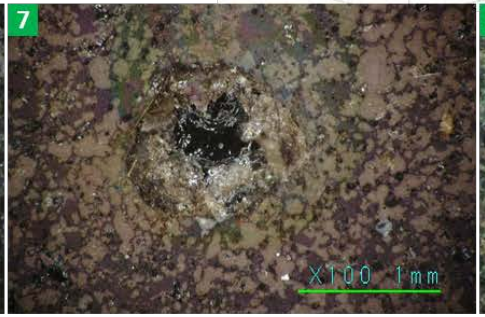
EFT-1 Post-Flight MMOD Inspection Results

Possible 6 MMOD impacts found on Orion tiles post-flight, 5 of which are >0.5mm deep



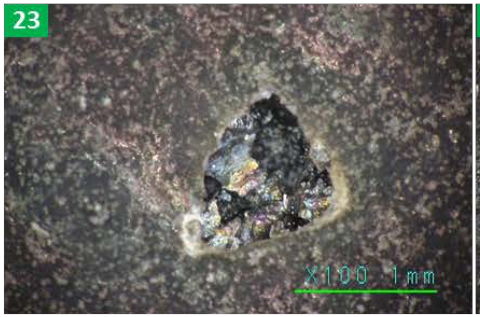


Panel A, Tile 33
Feature Size = 0.51 x 0.50 mm, Depth = 0.50 mm



Panel C, Tile 73
Feature Size = 1.29 x 1.10 mm, Depth = 0.05 mm

Panel H, Tile 144
Feature Size = 0.63 x 0.56 mm, Depth = 0.54 mm

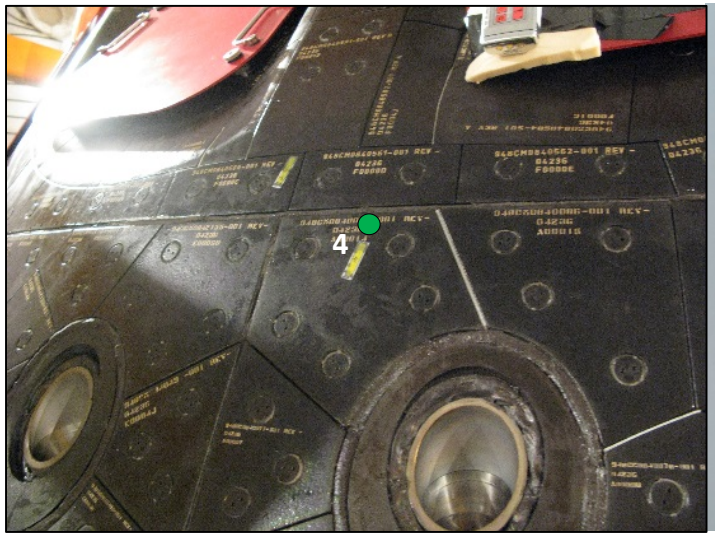


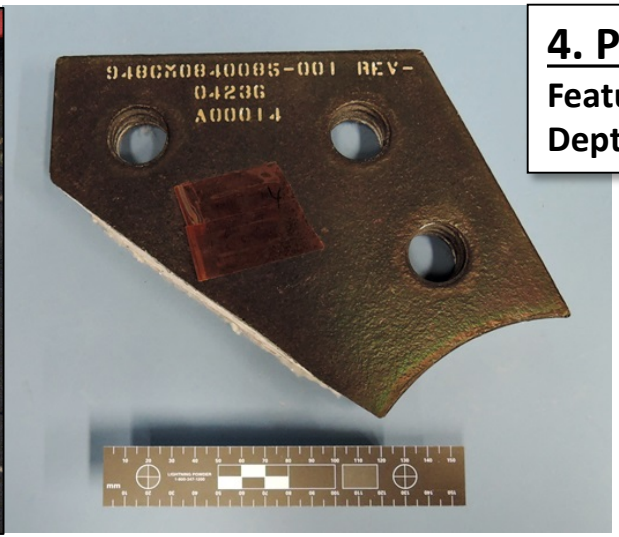
Panel I, Tile 45
Feature Size = 1.18 x 1.15 mm, Depth = 0.60 mm

Panel F, Tile 45
Feature Size = 1.06 x 1.02 mm, Depth = 1.02 mm

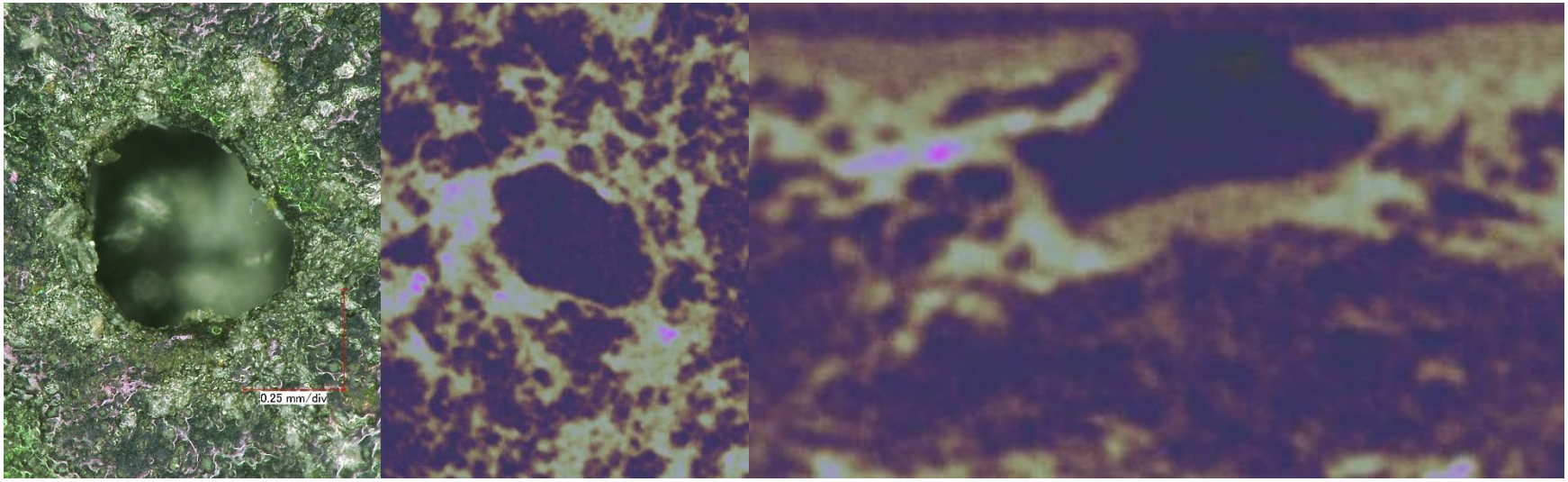
Panel A, Tile 8
Feature Size = 1.88 x 1.27 mm, Depth = 0.70 mm

Detailed CT scans of the Panel A tile



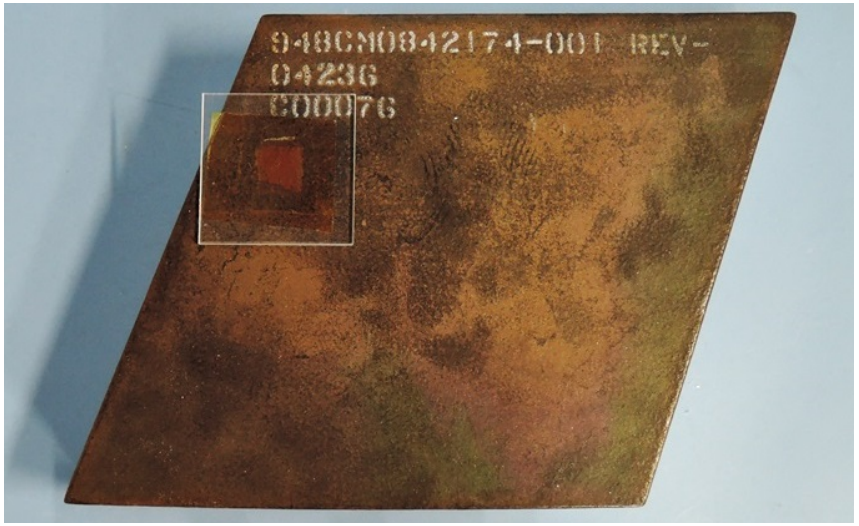


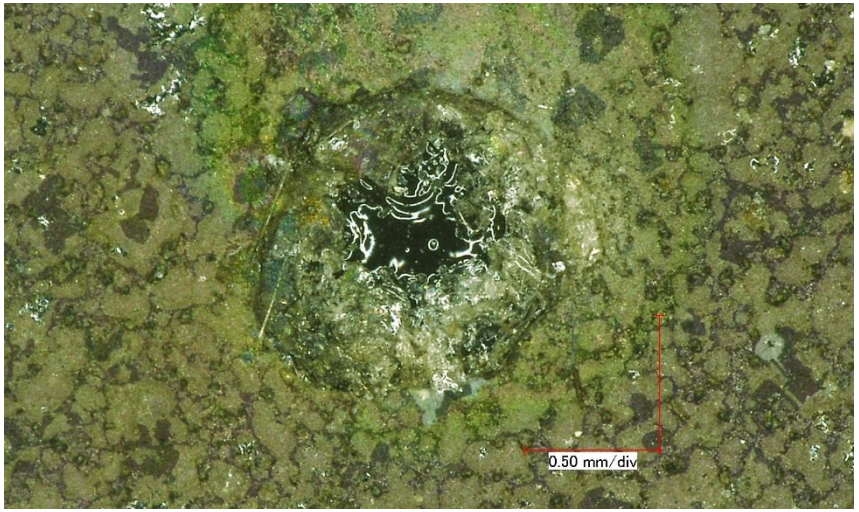
4. Panel A, Tile 33
Feature Size = 0.51 x 0.50 mm
Depth = 0.50 mm



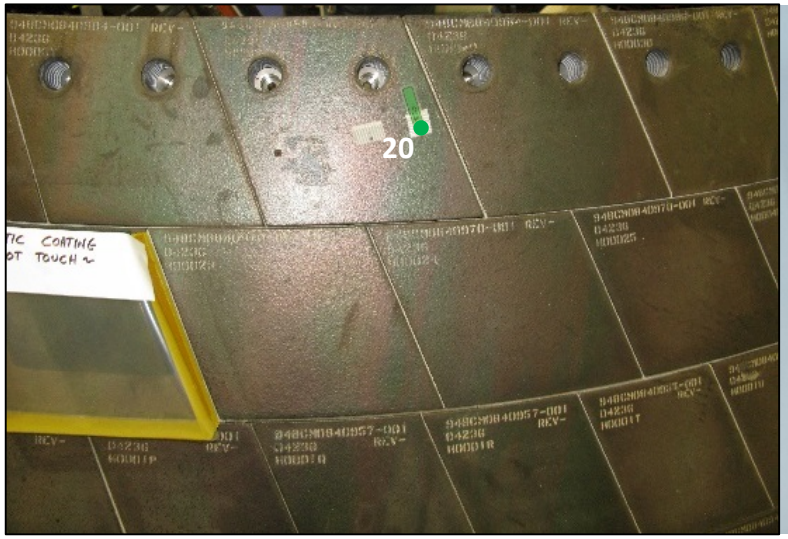
The Panel C candidate impact crater is very shallow and has a very smooth and specular reflective base

7. Panel C, Tile 73
Feature Size = 1.3 x 1.1 mm
Depth = 0.05 mm

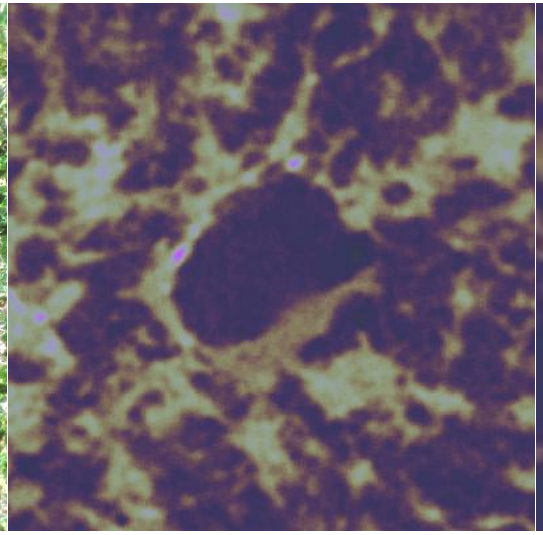


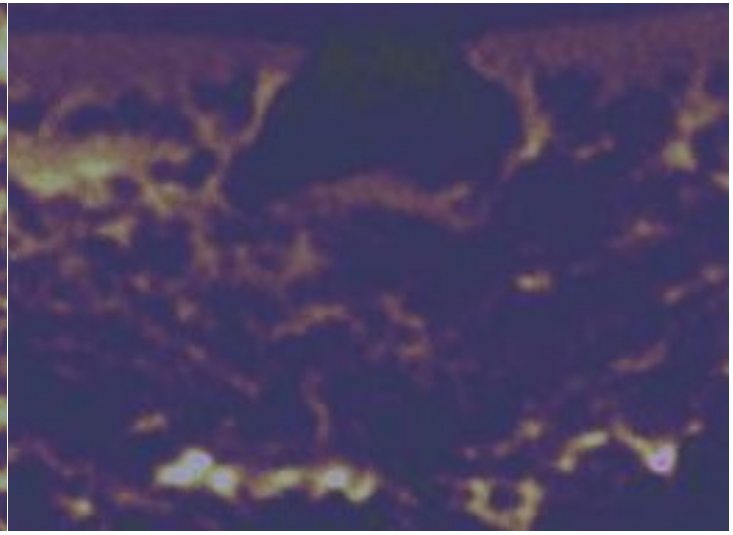


Detailed CT scan of the Panel H tile



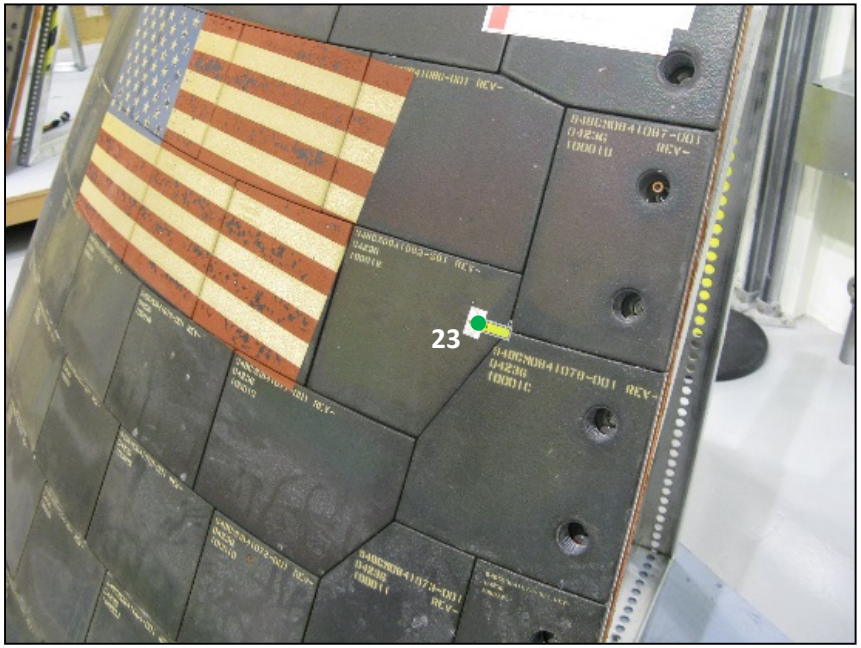
20. Panel H, Tile 144
Feature Size = 0.63 x 0.56 mm
Depth = 0.54 mm

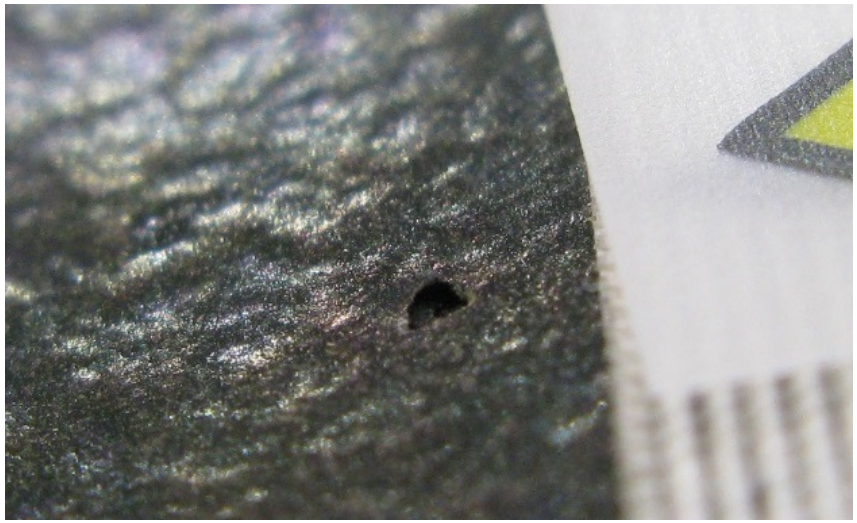


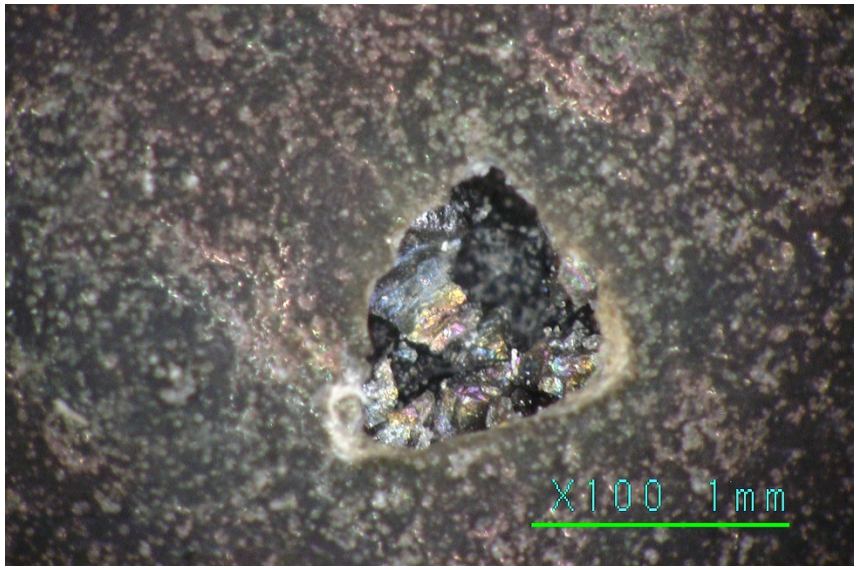


The Panel I candidate impact crater has been optically measured and preserved from destructive evaluation

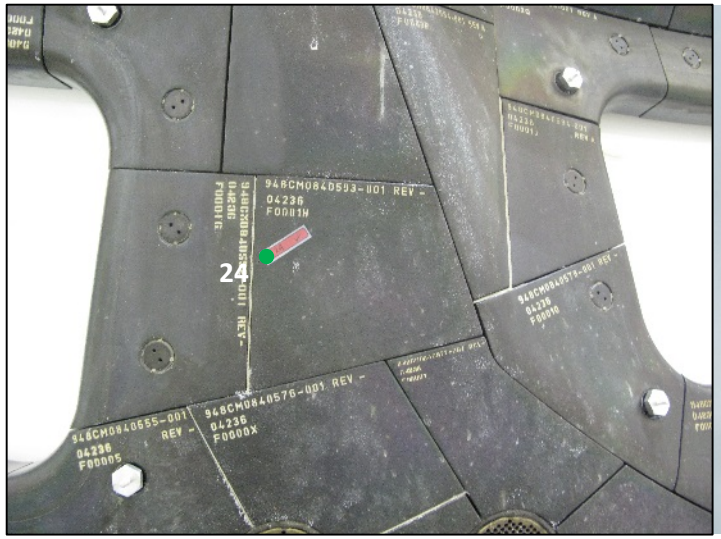
23. Panel I, Tile 45
Feature Size = 1.2 x 1.1 mm
Depth = 0.60 mm



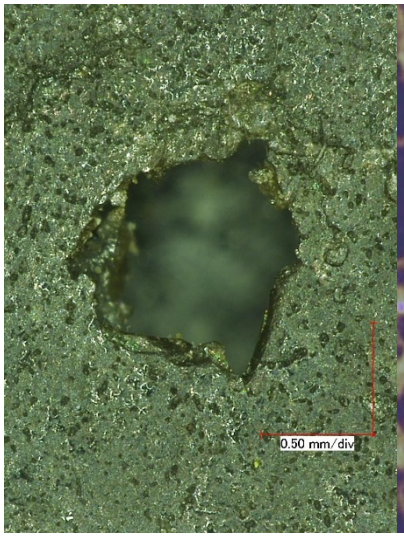


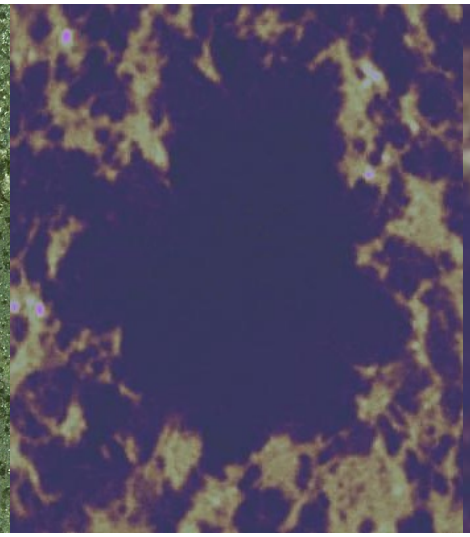


Detailed CT scan of the Panel F tile

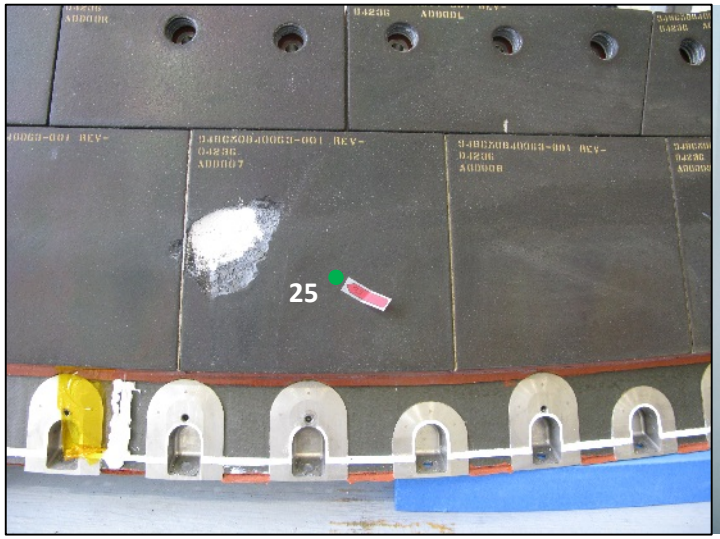


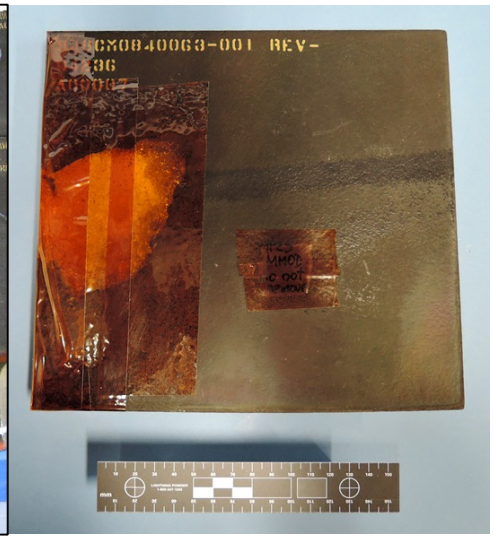
24. Panel F, Tile 45
Feature Size = 1.1 x 1.0 mm
Depth = 1.02 mm



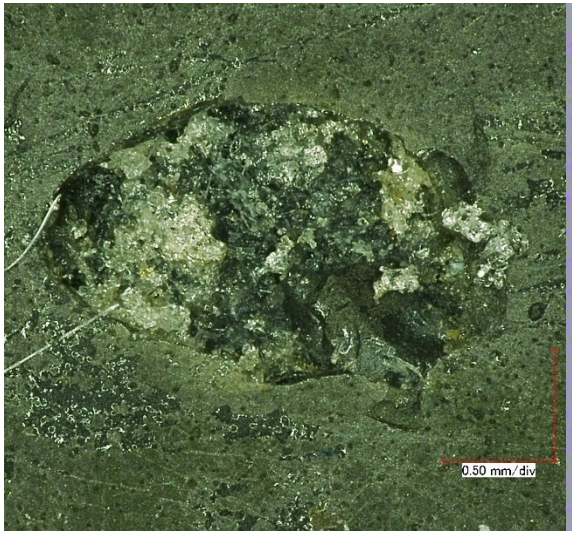


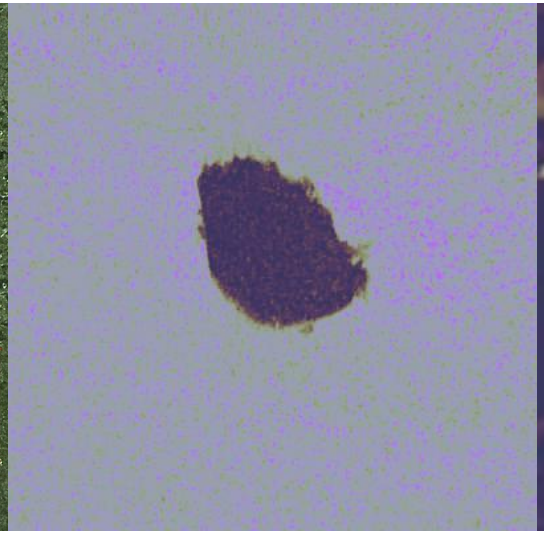
Detailed CT scans of the second Panel A candidate crater

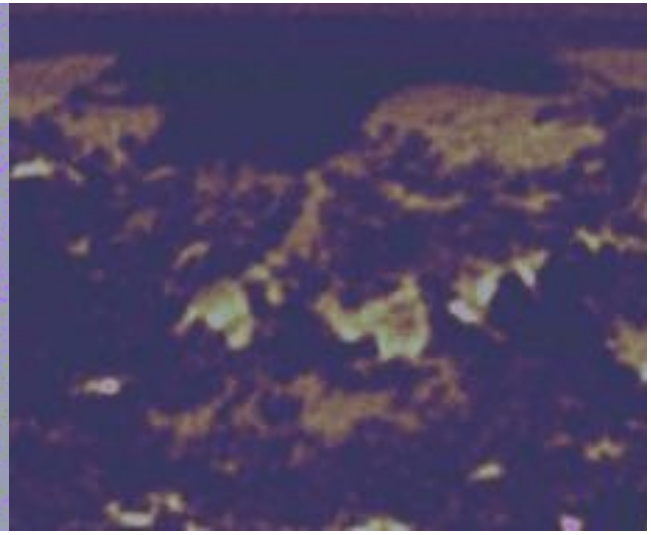




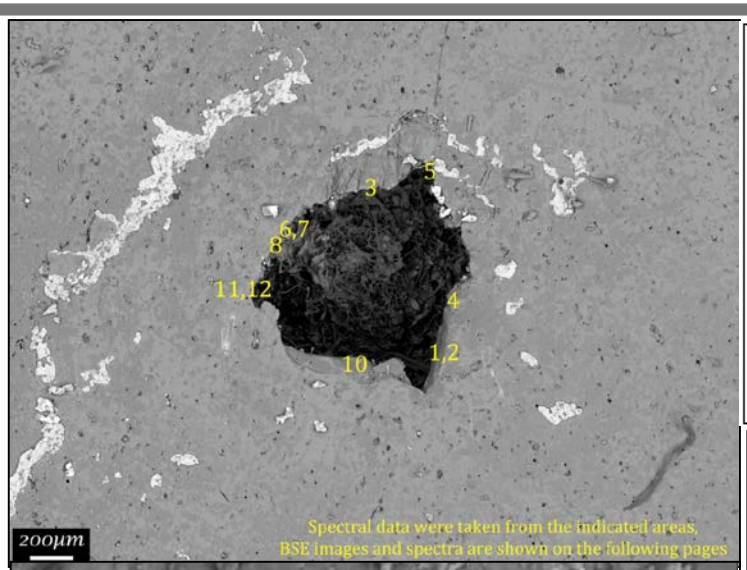
25. Panel A, Tile 8
Feature Size = 1.88 x 1.27 mm
Depth = 0.70 mm

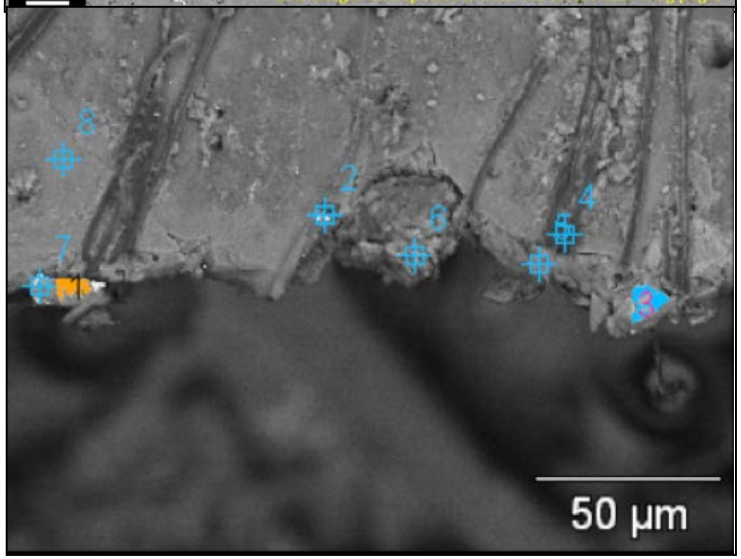


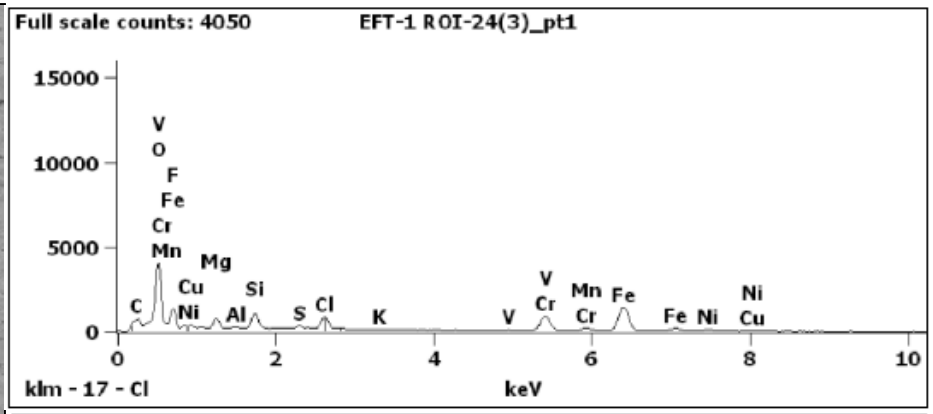


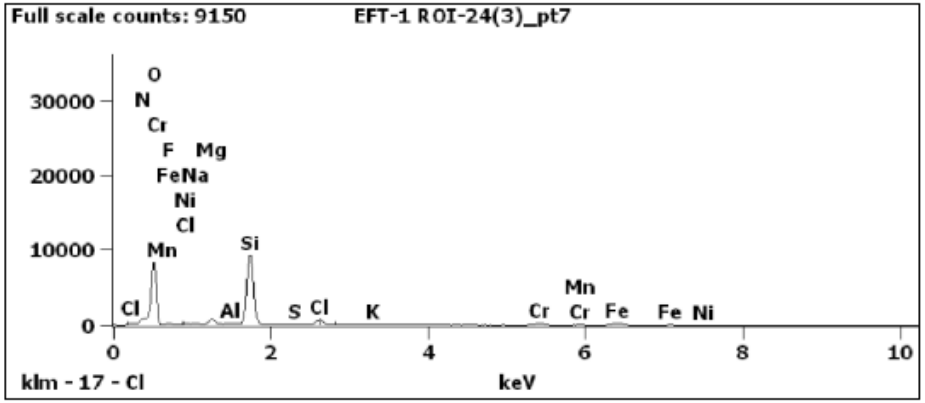


SEM spectrum measurements are being performed to identify remnants of the impacting body





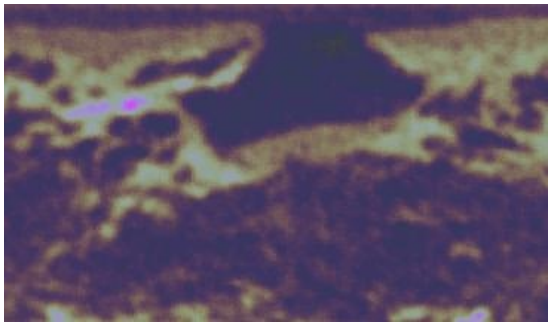




Spectrum 1: ***Iron, chromium, nickel, vanadium, copper****, and minor AETB and salts.*
Spectrum 2: ***Barium, iron****, and minor AETB and salts*
Spectrum 3: ***iron oxide****, and minor AETB and salts*
Spectrum 4: AETB and salts
Spectra 5-6: AETB, salts, and minor ***titanium*** *and/or* ***iron***
Spectrum 7: AETB and salts, ***iron, chromium, nickel***
Spectrum 8: AETB

Hydrodynamic simulations are used to see how impact conditions affect crater morphology

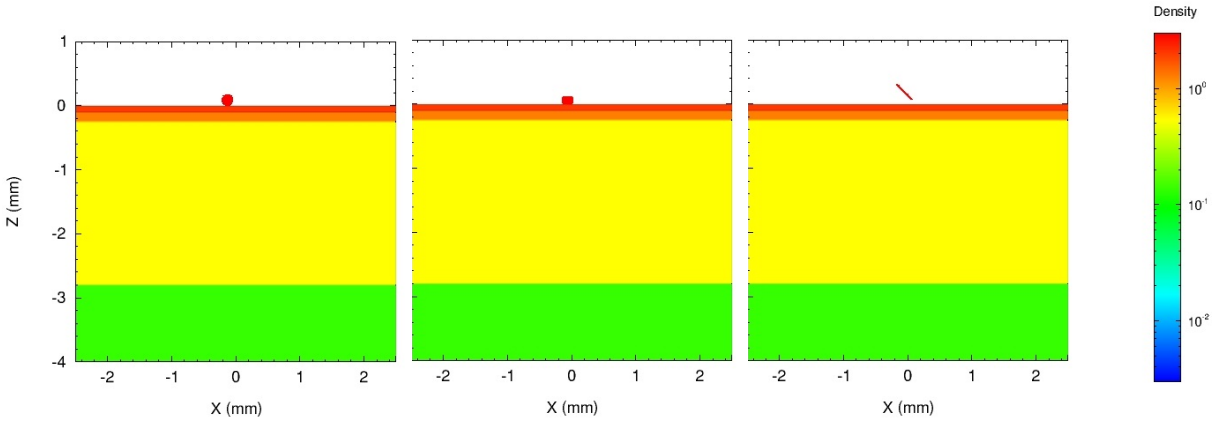
Panel A candidate crater



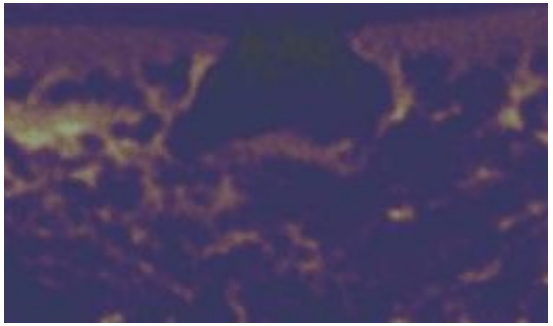
0.18D mm SS Sphere
3 km/s & 55°

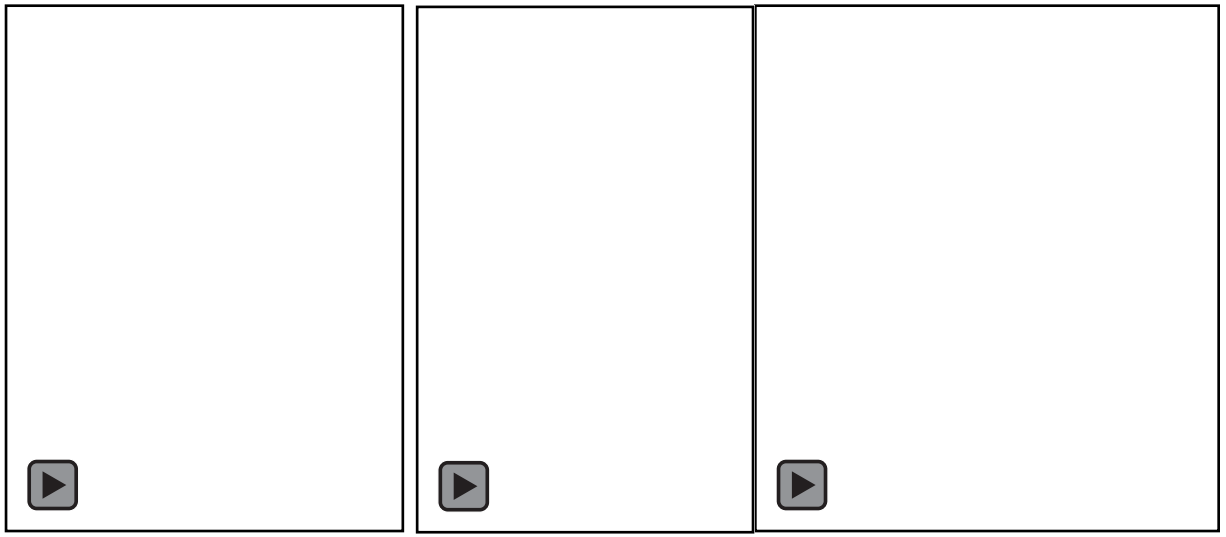
0.18Dx0.12 mm SS Cyl
3 km/s & 55°

0.36Dx0.03 SS Cyl
3 km/s & 55°

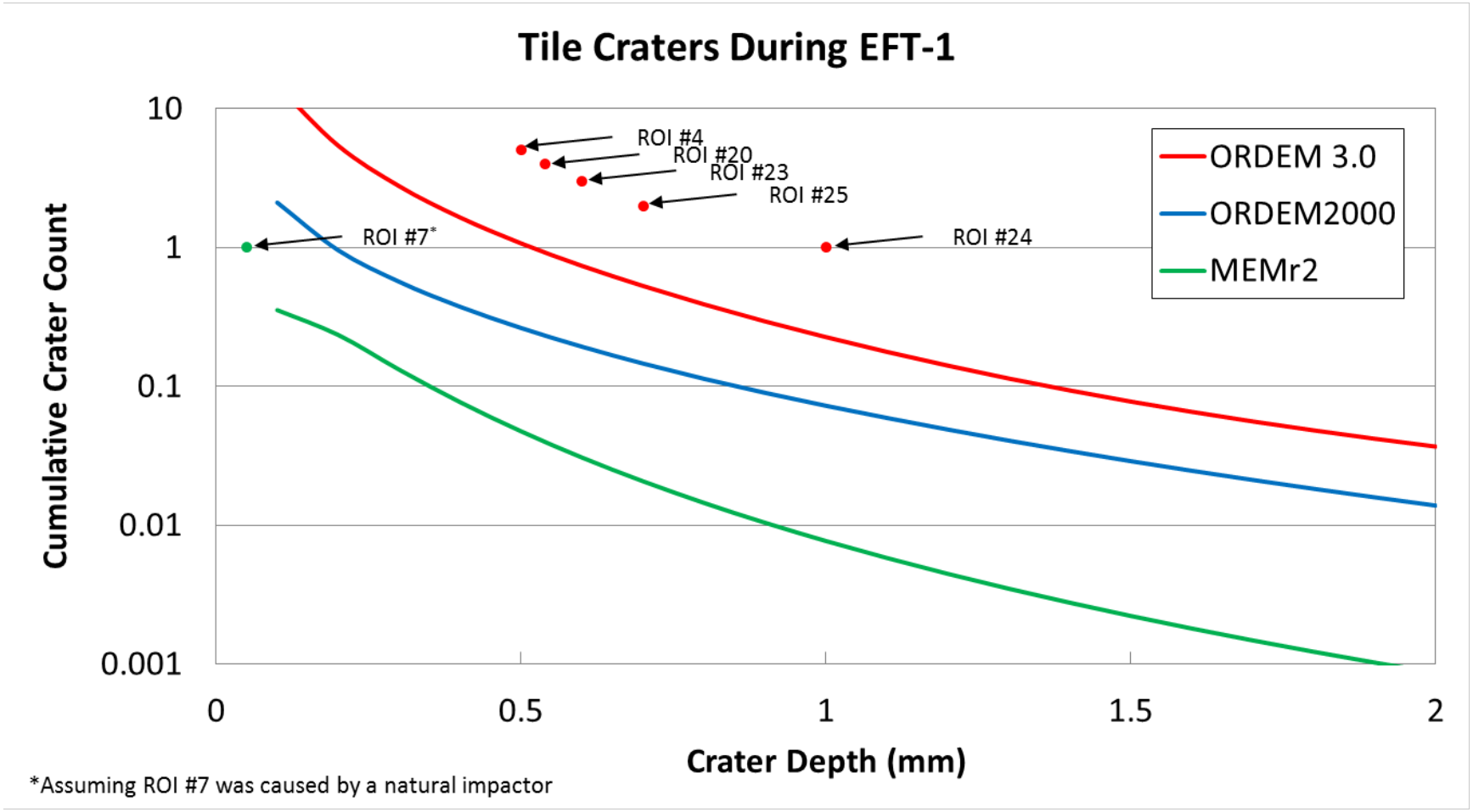


Panel F candidate crater





Environments can be examined pending verification of the impact craters and performance of the tile



Environment model extrapolations are within order of magnitude of observations

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- Orion's ascent fairing, backshell and landing recovery system design provide a nearly pristine return surface of in-flight solid particle impacts
- Orion's EFT-1 mission profile took the vehicle into some of the highest density debris bands surrounding the Earth beyond where most returned surfaces have ventured
  - Pre-flight preparatory ground based testing demonstrated the anticipated crater characteristics for particles in the sub-millimeter size range
  - Pre- and post-flight visual inspections identified six candidate impact craters with characteristic dimensions in the millimeter range
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  - Hydrodynamic simulations consider impact speed, obliquity and shape effects