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CRATER MORPHOLOGY OF PARTICLE IMPACTS ON GERMANIUM SURFACES FLOWN ON LDEF - A COMPARISON WITH LABORATORY EXPERIMENTS

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ABSTRACT

The Lehrstuhl für Raumfahrttechnik (LRT) received several germanium surfaces of the LDEF experiment A0187-2 "Chemical and Isotopical Measurements of Micrometeoroids using Secondary Ion Mass Spectrometry", which were exposed to low earth orbit conditions for approximately 69 months. This paper describes the analyses of the crater morphology of impact features on these surfaces using 3D-surface laser profilometry and their comparison with hypervelocity impact experiments performed in the laboratory of the LRT. Particle kinetic energy vs. crater volume, central crater diameter vs. spallation zone diameter and crater depth vs. crater volume relationships are described. Crater cross-sections for impacts with different particle speeds are given, as well.

1. LDEF SURFACES

After retrieval of the LDEF satellite, the LRT received nine Ge surfaces from experiment A0187-2 "Chemical and Isotopical Measurements of Micrometeoroids using Secondary Ion Mass Spectrometry" from bay E08, which were located at the satellite's near-ram direction.

1.1 Experiment Description

The experiment was designed to retrieve microparticle material from space for chemical analysis. The germanium surfaces were covered with a thin foil that would cause an impacting particle to break up and thus produce a spray pattern on the Ge with a relatively high amount of particle residue (see figures 1 and 2).

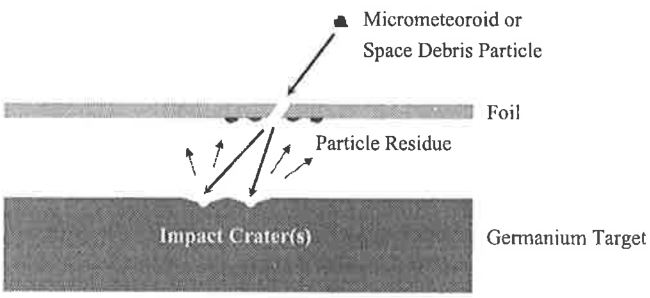

Figure 1. Sketch of Experiment A0187.

Unfortunately, none of the foils from the leading edge surfaces were still intact after retrieval. These foils were already destroyed while LDEF was in orbit. Therefore, the majority of impacts were conventional hypervelocity impacts with apparently no foil interaction (see figures 2 and 3 for examples of impact types).

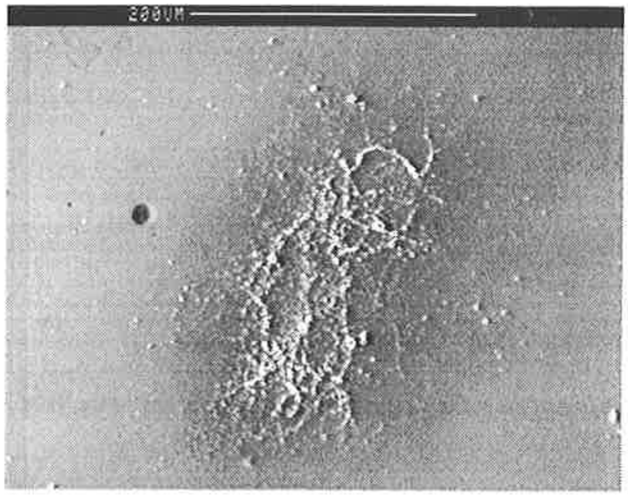

Figure 2. "Extended impact" with obvious foil interaction due to Particle debris spray.

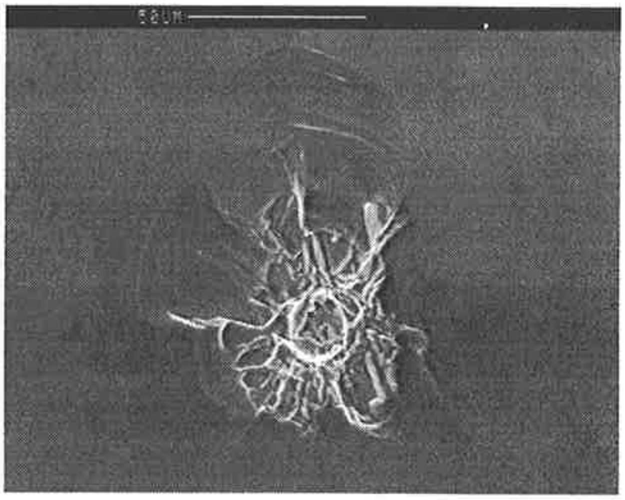

Figure 3. Conventional hypervelocity impact with obviously no foil interaction since no particle residue spray can be seen.

1.2 Analyses of the Germanium Surfaces

It showed that surface analysis techniques, such as EDX or WDX, could not give information on the chemical composition of the particles that impacted, because a thin film of Si caused by outgassed RTV coated the surfaces.

Additionally, the high number of conventional hypervelocity impacts on the leading edge surfaces with their relatively small amount of particle residue suggested investigations on the morphology of those impacts rather than on characterization of the chemical composition of the impactors.

The LDEF germanium surfaces are scanned for impact features down to 5 µ central crater diameter using an SEM. The frequency data of figure 4 resembles this resolution.

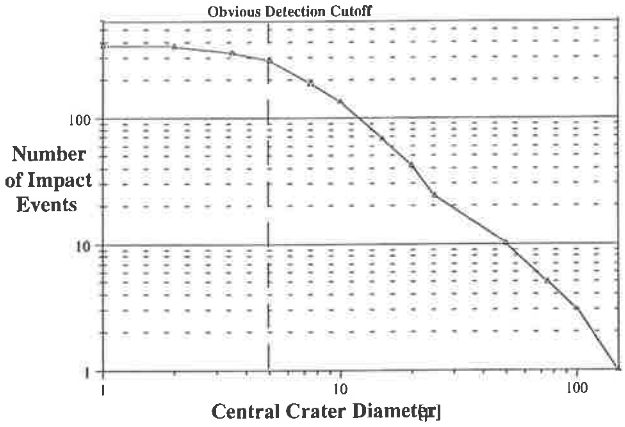

Figure 4. Frequency of impact features found during the SEM scans.

After the impact features are located, their topography is analyzed using three-dimensional laser profilometry. For this a Rodenstock RM600-3D with a vertical resolution of approximately 0.5 µ with a vertical measurement range of 0.6 mm is used. Results are given as a set of z-coordinates with typically 1000 data points per mm along the measurement axis and 2 µ offsets between each profile.

1.3 Known Impact Parameters for LDEF surfaces

The SEM scans and the 3D-scans provide information on

- central crater depth,
- diameter,
- spallation zone volume, and
- profile data of crater cross-section

of the impacts on the LDEF germanium surfaces.

2. LABORATORY EXPERIMENTS AT THE LRT

To get calibration data, impact tests on Germanium surfaces were performed at the laboratory of the LRT.

2.1 The Plasmadynamic Accelerator Facility at the LRT

The Plasmadynamic Particle Accelerator of the LRT was used to obtain calibration data on the morphology of impact features of hypervelocity particles into germanium. The accelerator can launch glass spheres with masses between $1 \cdot 10^{-14}$ kg to $1 \cdot 10^{-9}$ kg and velocities between 2 and 20 km/s. A sketch of the accelerator facility is shown in figure 5.

2.2 Description of the Laboratory Experiments

The particle velocities and masses of the experiments performed so far are given in figure 6. Maximum particle velocity was 17 km/s (with a particle mass of $1.8 \cdot 10^{-012}$ kg); the maximum mass reached was $8.5 \cdot 10^{-010}$ kg (at 5.1 km/s).

Additionally, crater topography scans provide crater cross-sectional data and crater volume and depth information.

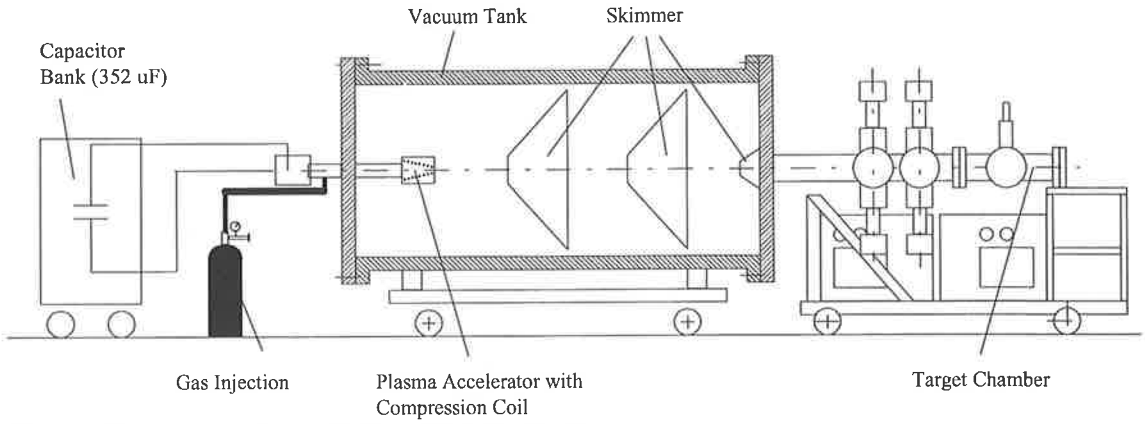

Figure 4. The plasma accelerator facility at the LRT, Munich.

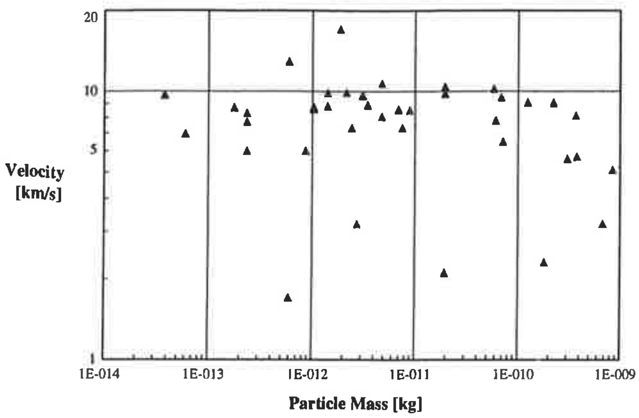

Figure 6. Mass and velocity of particles of laboratory experiments performed so far.

2.3 Known Impact Parameters for Laboratory Experiments

The laboratory experiments provide information on particle velocity by time-of-flight measurement and particle mass by measuring the diameter of the particle's penetration hole of a sub-micron foil in front of the target surface.

Crater dimensions are obtained by microscope analysis and laser topographic analysis.

- Particle mass,
- particle velocity,
- particle shape (spherical), and therefore
- mass (glass),
- central crater depth, and
- diameter,
- spallation zone volume, and
- profile data of crater cross-section.

Only the last four parameters can be determined for both LDEF and laboratory impact features.

3. ANALYSIS OF DATA

The laboratory data can be used to obtain relationships between crater geometry and physical properties of the particle and target material. The scanning data is used to set up relationships between crater geometry and particle properties.

3.1 Spallation Zone Size

This relationship allows an estimate of the total damage occurring on brittle surfaces as opposed to ductile surfaces. It may also be used to obtain scaling information for different surface materials.

Using a quasi-linear log-log fit, the relationship between particle diameter and average spallation zone diameter for glass spheres impacting germanium with velocities between 2 and 17 $^{km}/_{s}$ can be given as (see also figure 7):

$$\log_{10} D_{Spall} = 1.262 + 0.881 \cdot \log_{10} D_{Particle} \qquad (1)$$

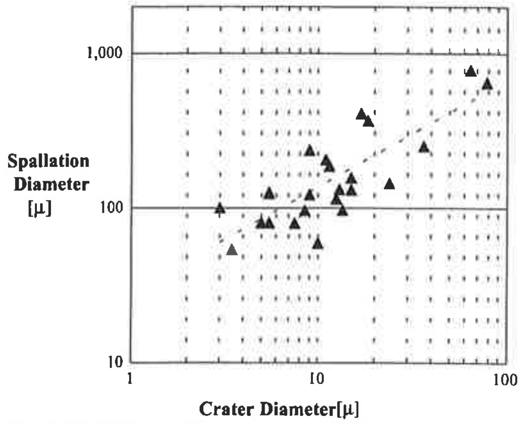

Figure 7. Relationship between particle size and "damage", i.e., average spallation zone diameter, for laboratory experiments.

3.2 Particle kinetic energy relations

Some other geometry data correlates with particle properties. One of the relationships, particle kinetic energy vs. total spalled off crater volume, is shown in figure 8 together with data for impacts into Au and Al (see [3]).

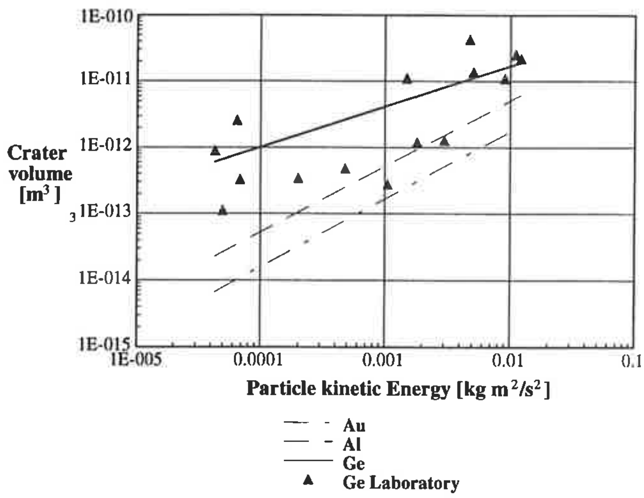

Figure 8. Particle kinetic energy vs. crater volume from laboratory experiments.

These relationships may be used for scaling between impacts that occurred on different surface materials on the LDEF satellite, such as Aluminum and Gold. The relation is given as

$$V_{crater} = a \cdot E_{particle,kin}{}^{b} \qquad (2)$$

The values of the constants a and b, respectively, are given in Table 1.

material	a	b
Al	$4.8 \cdot 10^{-10}$	0.99
Au	$1.9 \cdot 10^{-10}$	1.02
Ge	$2.78 \cdot 10^{-10}$	0.61

Table 1. Constants for equation 2 for different surface materials. Al and Au parameters from [3].

3.3 Crater cross-sections

Apart from that, the crater cross-section geometry varies with particle velocity, as well. The following three figures show crater cross sections of laboratory experiments for three different particle velocities. Apparently, the central crater rim becomes more and more significant with the particle velocity becoming faster as melting in the central crater region can be observed for impacts formed by particles faster than 6-7 $^{km}/_{s}$.

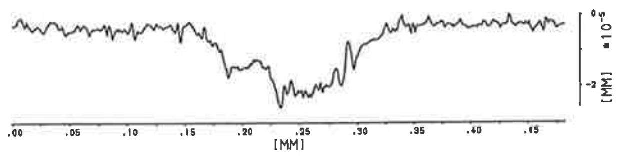

Figure 9a. Cross-section of an impact with particle velocity of 2.1 $^{km}/_{s}$

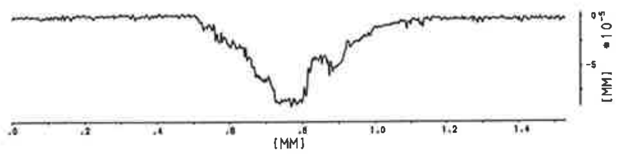

Figure 9b. Cross-section of an impact with particle velocity of 5.6 $^{km}/_{s}$

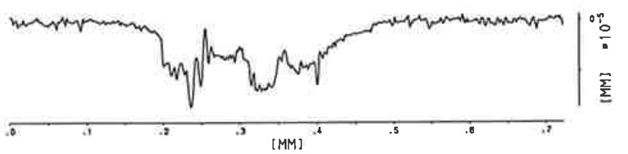

Figure 9c. Cross-section of an impact with particle velocity of 7.8 $^{km}/_{s}$

The analysis of the LDEF impact feature cross-sections could provide velocity information of the impactors.

3.4 Crater geometry data

When looking at the available crater geometry data of the LDEF impacts, an interesting relationship between crater dimensions can be seen: plotting crater depth or central crater diameter vs. spalled off crater volume yields two distinct clusters of data points (fig. 10). Laboratory data added neighbors the upper of the two clusters (fig. 11).

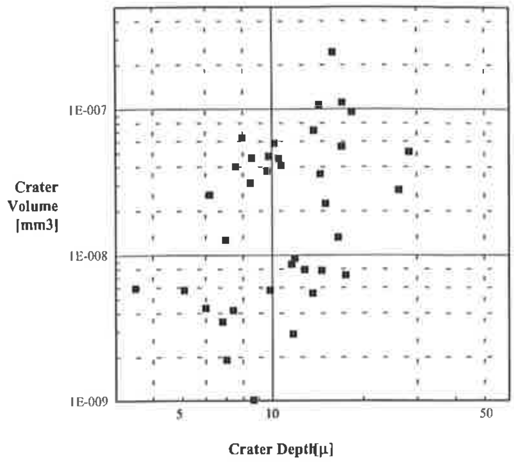

Figure 9. Crater geometry relation for LDEF craters.

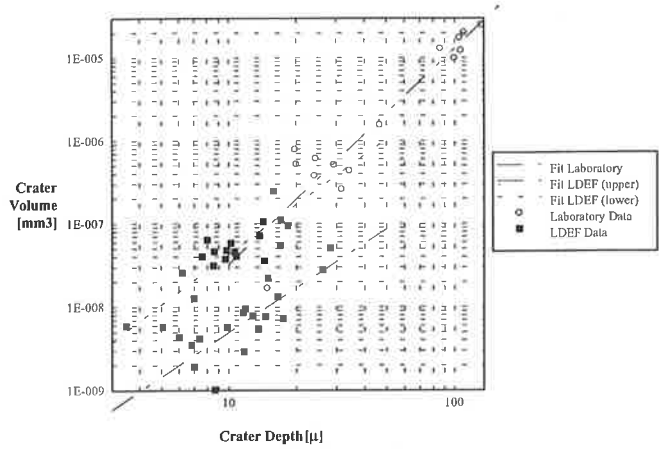

Figure 11. Crater geometry relation for LDEF and laboratory craters

The two different clouds visible in figure 11 might be due to different particle parameters. The reason for this clustering is not yet known; it might be due to separate distinct velocities or particle densities or masses. Further investigations will have to focus on this item.

4. CONCLUSION

A close look at crater morphology of impact craters found on LDEF surfaces and of hypervelocity impacts produced in the laboratory of the LRT, Munich, are used to reveal more information on particle properties, such as mass and velocity in near earth space. The following observations were made:

- Particle diameter and average spallation zone diameter correlate.
- Crater volume to particle kinetic energy relationships should be used for scaling of impact events on different surface materials found on LDEF.
- Cross-sections of craters should reveal information on impact velocity.
- Some crater geometry parameters correlate with particle or material properties in a not-yet understood manner.

Comparing volume-to-kinetic energy relationships for hypervelocity impacts into germanium with those for aluminum, gold or other materials used on LDEF might provide a way for scaling between impact events on those different surfaces and should lead to better understanding of the particle environment.

The aim of these investigations is to develop a particle velocity and/or particle density model for near earth space covering the particle size regime from approx. 1 μ diameter particles to about 10 μ diameter particles.

Investigations will have to gather more data on both laboratory impacts and impacts on the Ge surfaces from LDEF.

5. NOTE

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6. REFERENCES

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