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# CHEMICAL CHARACTERIZATION OF IMPACT DEPOSITS ON SPACE-EXPOSED MATERIALS BY MEANS OF SECONDARY ION MASS SPECTROMETRY

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## ABSTRACT

Satellites in low earth orbit are bombarded by a variety of different projectiles both of natural and man-made origin. In order to distinguish between these two types of particles a chemical analysis of impact deposits can be made. It is shown that secondary ion mass spectrometry is particularly suited for this kind of investigation and that it is in many cases clearly superior to the scanning electron microprobe with energy-dispersive x-ray analysis.

## 1. INTRODUCTION

The Long Duration Exposure Facility (LDEF) was placed into orbit in April 1984 and was retrieved in January 1990. On board this 10 m-long, nearly cylindrical satellite were 57 space experiments, designed to gather scientific data and to test the effects of long-term space exposure on spacecraft materials, components, and systems. Among the most noticeable effects of the space environment on spacecrafts is the permanent bombardment by small particles with velocities of several km/s. In order to assess possible hazards to space flight posed by such impacts, it is important to determine (a) the absolute number of impacts and (b) the ratio of natural (micrometeoroids) to man-made (orbital debris) impact particles. Various attempts have been made to estimate this ratio, e.g., by comparing particle fluxes on differently oriented LDEF surfaces. However, a more direct approach to this problem is based on the chemical characterization of particle residues. Since micrometeoroids and orbital debris particles have distinct physical and chemical properties, it is possible to estimate the relative contribution of either type to the total particle flux by analyzing impact debris on LDEF surfaces.

## 2. DESCRIPTION OF ANALYZED SAMPLES

All outer surfaces of the LDEF satellite are covered by impact features of various types and sizes. All impacts larger than 0.5 mm on the surface of LDEF have been documented in great detail by the "Meteoroid and Debris Special Investigation Group" at the Kennedy Space Center right after the retrieval of the satellite (Ref. 1). What can be seen in this documentation are the optically visible *effects of hypervelocity impacts*, such as craters, dents, and cracks. Due to speeds of typically several km/s on impact, practically no projectile material survives the collisions unaltered and only rarely are chunks of projectile material large enough for energy dispersive x-ray analysis (EDX) found within or in the vicinity of impacts. However, there is a thin layer of impact debris around most impact features where some fraction of the particle material re-condensed after being vaporized during impact. This debris layer is generally too thin to be seen in either optical or scanning electron microscopes (SEM), but secondary ion mass spectrometry (SIMS) can be used to analyze this material even when its thickness is only a few atomic monolayers.

Impacts on all surfaces can be analyzed in order to determine the nature of the projectile material. However, in this study the analyses were first focused on surfaces of the capture cell experiment A0187-2, which was specifically designed for this kind of investigation (Ref 2). The principle of this experiment is shown in Figure 1. A target plate is covered by a thin foil separated by a small distance. A high velocity dust grain of sufficient size penetrates the foil and may be disrupted in the process, spreading out into a debris shower. This shower impacts the target plate and is further disrupted, melted and vaporized. The projectile material ejected from the impact zone is collected on the backside of the foil and on the surrounding area of the Ge plate.

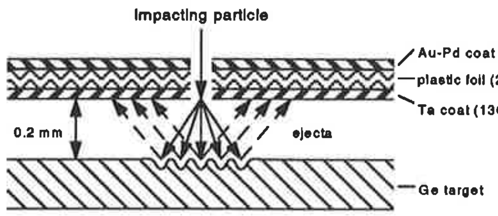


Figure 1. Schematic of capture cell experiment A0187-2.

The reasons for choosing samples from the capture cell experiment A0187-2 are the following: 1) the target material (germanium wafers) is of very high purity, which is critical for the determination of the deposit composition; 2) the very design of the experiment, with the cover foil disrupting the particle before the impact, increases the amount of projectile material retained on the surfaces; 3) previous calibration experiments on identical capture cells with simulated impacts created a valuable database for comparison and normalization (Ref. 3).

## 3. INITIAL CHARACTERIZATION

Preliminary optical microscope examination of the capture cells from experiment A0187-2 showed numerous "extended impact features", which resembled laboratory simulation impacts produced by projectile material that had penetrated plastic foils and had suffered disruption. Systematic analyses by secondary electron microprobe (SEM) indicated that four different types of extended impact features were found on the germanium plates that could be used for classification (Ref. 2): 1) craters surrounded by deposits, 2) ring-shaped features, 3) "spider webs" consisting of thousands of small craters, and 4) features consisting of one or more larger craters in a spray of smaller craters. All types of impacts were included in the more detailed SIMS analyses.

## 4. DETAILS OF SIMS ANALYSES

SIMS is a highly-sensitive micro-analytical technique for surface characterization and depth profiling. It uses a focused ion beam that sputters the sample surface and creates secondary ions which can be analyzed in a mass spectrometer (Fig. 2). SIMS can be used for the quantitative determination of all elements (including H) and allows the measurement of isotopic ratios. The detection limits vary by several orders of magnitude for different elements but are as low as several ppb for a number of elements. The lateral resolution of SIMS depends mainly on the diameter of the primary beam and can be better than 1 µm.

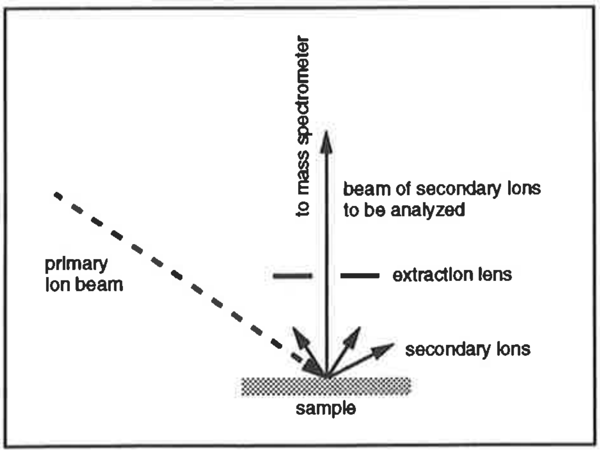


Figure 2. Principle of secondary ion mass spectrometry.

The SIMS analyses of the deposit composition on the LDEF surfaces are made in step scans across the impact features. At each step the chemical composition is measured with an $O^-$ primary beam of 1-2 nA that is rastered over an area of 40 µm x 40 µm. The width of individual steps are chosen between 35 and 60 µm each. Since each measurement consists of up to 50 steps, these traverses have typical length of several hundred µm and width of about 40 µm.

The count rates can be converted into relative elemental abundances by using SIMS sensitivity factors obtained from measuring standards with known compositions. The results represent the deposit composition at the analyzed spot; by comparing the measured compositions at different spots on the same traverse it is possible to gain some information on the lateral distribution of elemental abundances in the deposit (Fig. 3). Studies of laboratory impact experiments indicated that there can be significant elemental fractionation effects during the impact (Ref. 3). This has to be taken into account when the composition of the original projectile is calculated from the composition of the impact deposit.

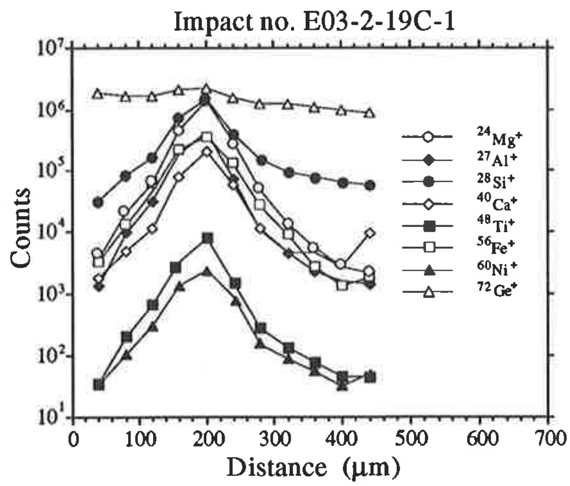


Figure 3. Count rates of different elements in a traverse across an impact feature on a Ge plate. The center of the impact is located near distance 200 µm.

## 5. RESULTS OF ANALYSES ON GE PLATES

To date more than 50 extended impacts have been analyzed by SIMS for the chemical composition of the projectiles. The count rates of the following elements were monitored during the scans: O, Mg, Al, Si, Ca, Ti, Fe, Ni, Ge, and Ta. These elements were chosen because they are the most abundant elements in cosmic dust particles or in the capture cells themselves. Ion signals associated with material from the impacts could be detected in almost all analyzed impact areas and it was possible to discern the most likely origins of the projectiles by comparing the compositions of the deposits to those of cosmic dust particles (Ref. 4) and well known man-made debris types. Thus it could be shown (Ref. 2, 5) that at least 75% of the impacts on the trailing edge of LDEF were caused by micrometeoroids while virtually all analyzed impacts on the leading edge were caused by man-made debris particles.

## 6. SIMS ANALYSES OF OTHER LDEF SURFACES

After establishing that SIMS is a powerful tool in the analysis of thin layers of impact deposits on the Ge capture cells, the same measurement technique was applied to other, less ideal surfaces from the LDEF satellite. Impacts on witness plates of high-purity Au from experiment A0187-1 appeared particularly interesting because debris analyses on these surfaces has already been performed by conventional SEM-EDX technique (Ref. 6). Unfortunately, in more than 50% of all analyzed Au impacts no impact deposit could be found with the SEM, which makes statistical interpretation of the data less reliable.

For SIMS measurements the Au impacts posed some analytical problems: The impacts in the Au foil are generally relatively deep and are surrounded by a "lip" of Au that rises above the original sample surface. Since SIMS requires a flat sample surface it was necessary to develop a new sample preparation technique for these kinds of impact craters. It was possible to flatten both the lip and the crater in a way that surfaces from inside the crater walls became accessible for the SIMS measurements on a flat surface. After these preparations, the SIMS scanning technique was applied to these Au witness plates.

First results of this ongoing investigation show that it is indeed feasible to measure deposit composition on Au samples and determine likely projectile origins even in cases where the SEM-EDX technique was not able to detect any residue. If applied to a larger number of Au samples, SIMS measurements can significantly improve the database of particle origins.

## 7. CONCLUSIONS

SEM studies of impact features on various LDEF surfaces show that most particles were completely destroyed during the impact event. In more than 50% of all impacts it is not possible to detect any residue and determine the particle origin with conventional SEM-EDX methods. However, with the surface-sensitive SIMS technique thin layers of debris can be analyzed in a significantly larger number of impacts. Recent results prove that SIMS can be used on a variety of different target materials. Thus SIMS may be the best available technique for the identification of projectile origins.

## 8. REFERENCES


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