MEASUREMENTS OF THE ELEMENTAL AND ISOTOPIC COMPOSITION OF INTERPLANETARY DUST COLLECTED ON LDEF

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ABSTRACT: A passive interplanetary dust collection experiment, currently in orbit aboard LDEF (Long Duration Exposure Facility), is described. The collectors, germanium target plates covered by metallized Mylar foils, are designed for secondary ion mass spectrometry (SIMS) measurements of the elemental and isotopic compositions of residues resulting from micrometeoroid (> 10^{-10} grams) impacts. Impact simulation experiments have demonstrated the validity of the collection concept. Quantitative elemental analyses are complicated by the non-uniform distribution of projectile-derived elements.

1. INTRODUCTION

The Long Duration Exposure Facility (LDEF), deployed by Space Shuttle (STS-13) in April, 1983, and scheduled for retrieval in February, 1984, carries 57 science and technology experiments [1]. One such experiment, described here, is designed to collect residues from impacting interplanetary dust particles for laboratory measurement of elemental and isotopic compositions [2]. In addition, the experiment will provide information on the flux and size distribution of micrometeoroids.

Isotopic measurements are the prime experimental objective. Such measurements, performed on interplanetary dust particles collected in the stratosphere, have shown already that interplanetary dust is primordial in the sense that some isotopic ratios differ from the average solar system values [3]. Orbital dust collections are complementary to stratospheric collections because different particle selection effects exist. Orbital collections also provide an opportunity to collect interstellar particles which are not expected to survive atmospheric entry because of their high velocities.

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2. EXPERIMENTAL DESIGN

A total of 240 capture cells are deployed covering an area of 2 m^2 distributed equally on the trailing and leading surfaces of the gravitationally stabilized LDEF structure. Each of the 240 cells (figure 1) consists of a pure, polished Ge target plate and a 2.5 μm thick Mylar foil separated by 0.2 mm. The cover foil is coated with 100Å of Au/Pd on the space-facing surface, to prevent erosion of the plastic by the residual atmosphere at LDEF orbital altitudes [4], and 800Å of Ta on the Ge-facing surface, to facilitate chemical microanalyses. The choice of the materials (Mylar, Ge, Ta and Au/Pd) was based on considerations of chemical purity, mechanical and thermal properties, and economy. At impact velocities ~10 km/sec, particles break-up, melt, and/or vaporize during penetration of the foil and subsequent impact on the Ge. The resulting residues/impact ejecta are deposited on the Ge and the underside of the foil. Approximately 100 particles greater than 10 μm in size are expected to be captured by these collectors during LDEF's 10 months in orbit.

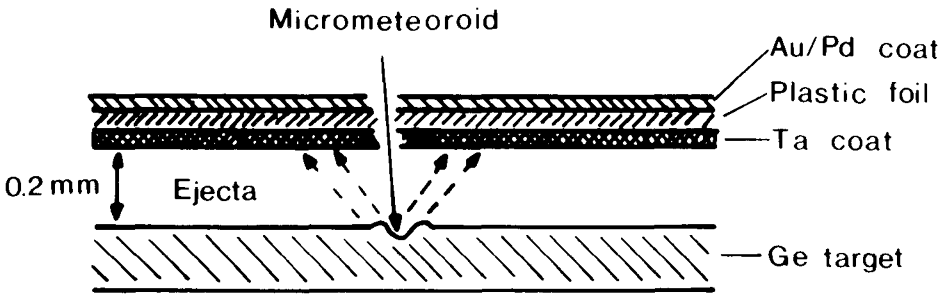

Figure 1

Collection principle for micrometeoroid collectors aboard LDEF.

The collected particle residues will be analyzed by a variety of techniques to determine the isotopic, elemental and physical characteristics of interplanetary dust. Emphasis will be placed on the measurement of isotopic ratios of selected elements (C, Mg, Si, S, Ca, Fe, Ni) by secondary ion mass spectrometry (SIMS). Elemental abundances will also be obtained by SIMS. Morphological studies of the impact and deposition regions will be performed in an SEM.

3. INITIAL RESULTS OF IMPACT SIMULATION EXPERIMENTS

Impact simulation experiments are being pursued in preparation for the return of the collectors. They are aimed at understanding the relationships between projectile characteristics (size, velocity, density and chemical composition) and impact structure morphology and they are also required to enable us to perform quantitative isotopic and elemental analyses of thin residues on the collector substrates. Another approach will be implantation of Ge substrates and Ta films with known doses of different ions ("marker ion technique" [5]).

Impact simulations are being conducted on 2.5 cm diameter collectors, similar in design to those on LDEF, bombarded in a plasma gun located at the Technical University, Munich. The Munich facility is capable of accelerating individual dust particles 50-100 µm in size to known velocities on the order of 10 km/sec.

SIMS analyses in a modified CAMECA IMS 3F ion microprobe are obtained by bombarding the specimen surface with O_2^+ ions to obtain positively charged secondary ions (for elements such as Na, Mg, Si, Fe) and with Cs^+ for negative secondaries (C, S). For elemental analysis, a the 3-dimensional distribution of projectile atoms is determined from depth profiles taken at regular intervals across the specimen surface. Isotopic measurements are made at high mass resolution to eliminate molecular interferences.

Test samples bombarded with glass (Na-rich and Corning lunar analog) and pyroxene particles 100 µm in size are currently being studied. After bombardment, the Mylar foil typically contains several large penetration holes (~100 µm) and hundreds of smaller holes (down to a few µm) each of which is associated with an impact region on the Ge. The small holes are produced by small particles which are secondary fragments broken from larger particles during acceleration in the plasma gun.

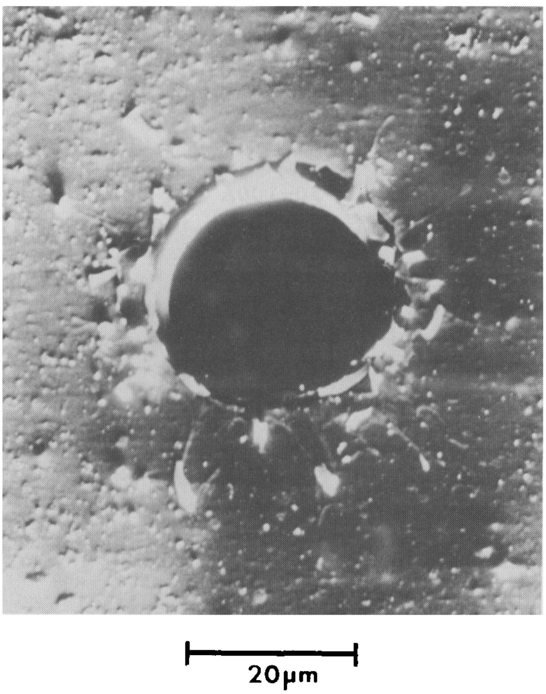

Figure 2:

SEM micrograph of penetration hole produced in tantalum coated Mylar by a glass particle accelerated by the Munich Technical University plasma gun. Tantalum, germanium and projectile fragments/residue surround the 20 µm diameter hole.

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3.1. Location of Impacts

Deposition halos on the plastic foil and Ge associated with penetration holes as small as several μm (figure 2) can easily be located with a low-powered, binocular microscope under oblique illumination. The impact structures on the Ge are particularly easy to identify because of their characteristic, concentric ring morphology (described below).

3.2. Secondary Ion Yields

Secondary ions from projectile residues can readily be measured with the ion probe for the major elements of interest (e.g., Na, Mg, Al, Si, K, Ca, and Fe). A typical traverse across a residue region on the Mylar foil produced by pyroxene is shown in figure 3. The ion signals are normalized to the $^{181}Ta^+$ signal from the substrate. The scans shown are obtained by integrating signals over an intermediate (~30–100Å) depth range from the depth profiles. The maximum $^{40}Ca^+$ signal was about 100 times higher than the background away from the impact feature. Similar scans are measured on the corresponding Ge structures.

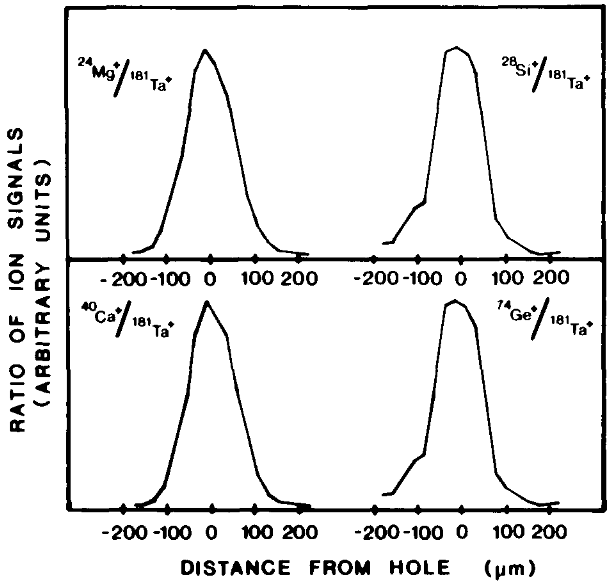

Figure 3:

Normalized plots of ionprobe signal from Mylar in the vicinity of projectile residue versus position for a depth interval of ~30–100Å and four different isotopes, ^{24}Mg, ^{28}Si, ^{40}Ca and ^{74}Ge. Regions containing projectile-derived residue are easily identified by well-defined signal maxima.

3.3. Spatial Distributions of Residues

Spatial distributions of the projectile residues vary considerably from element to element. Highly volatile elements (Na, K) tend to be distributed over a larger area around the impact location than lower volatility elements (Mg, Si, Ca, Fe). Consequently, elemental ratios vary with distance from the penetration hole.

3.4. Impact Structure Morphologies

Mylar: SEM observations of regions on the underside of the Mylar foil adjacent to penetration holes reveal abundant splashes and fragments. EDX analysis in these areas show only Ge indicating that Ge excavated by the impact dominates over the projectile elements.
Germanium: Impact regions on the Ge exhibit a variety of morphologies. Those corresponding to large holes (~100 μm) possess features typical of hypervelocity impacts, i.e. deep craters, extended spalled regions and ejecta-bearing rims. For holes less than about 30 μm in size the impact features consist of complex cell structures (figure 4). These structures are remarkably similar to that observed by McDonnell et al. [6] for an STS-3 impact on Kapton after penetration of a 5μm Al foil. This structural similarity indicates that these terrestrial shots simulate extraterrestrial events reasonably well. The small Ge impact structures

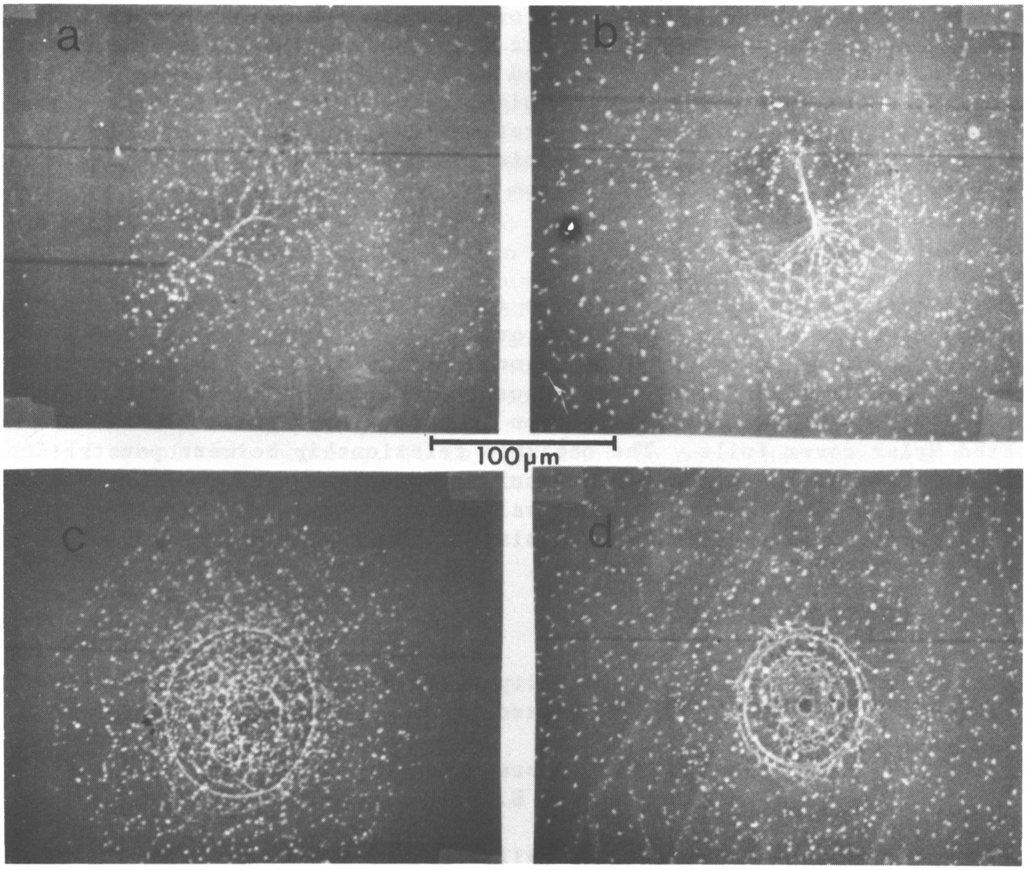

Figure 4:

Germanium impact structures for 4 projectiles with different penetration hole size, 11.3 (a), 12.0 (b), 13.3 (c) and 20.0 (d) microns.

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lack substantial relief, as would be expected for impact craters, and contain considerable amounts of projectile material. These observations show that small particles break up during penetration of the Mylar and impact the Ge as liquid and/or vapor in a dispersed jet of roughly conical shape. The morphology of the Ge structures relates systematically to penetration hole diameter (figure 4). Smallest holes (<10 μm) are associated with clusters of "etch pits" while holes ~ 20 μm in size correlate with well-developed cell structures terminated at the perimeter by well-defined rings. Still larger holes (~30 μm) relate to regions showing evidence of substantial excavation in addition to cells and rings.

3.5 Isotopic Measurements

Magnesium and silicon isotopic measurements have been made at high mass resolution on impact residues from the simulation experiments [2]. The results show the typical mass fractionation of SIMS analysis with isotopic ratios falling within several per mil of linear mass fractionation. Isotopic measurements are complicated by low ion signals during high mass resolution analysis and the rapid decline of the signal with time (depth) due to the thinness of the residue coating. This latter problem can be avoided by lateral step-scanning across the deposits during analysis.

4. CONCLUSIONS

These simulation results demonstrate that the LDEF collection/analysis concept is sound but also show that quantitative isotopic and elemental analyses are complicated by deposition heterogeneities. SIMS measurements of elemental and isotopic compositions of intercepted micrometeoroids should be possible on both Ge target plates and Ta-coated Mylar cover foils. The observed relationship between penetration hole size and impact structure morphology for simulation impacts suggests that information on the physical characteristics of impacting particles may be obtainable. Further simulation studies are required, however, to quantify such correlations.

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