

IMAGE AND COMPOSITIONAL CHARACTERISTICS OF THE LDEF "BIG GUY" IMPACT CRATER

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ABSTRACT

A 5.2 mm crater in Al-metal represents the largest found on LDEF. We have examined this crater by field emission scanning electron microscopy (FESEM), energy dispersive spectroscopy (EDS) and time-of-flight/secondary ion mass spectroscopy (TOF-SIMS) in order to determine if there is any evidence of impactor residue. Droplet and dome-shaped columns, along with flow features, are evidence of melting. EDS from the crater cavity and rim show Mg, C, O and variable amounts of Si, in addition to Al. No evidence for a chondritic impactor was found, and it is hypothesized that the crater may be the result of impact with space debris.

INTRODUCTION

The largest crater on LDEF measures 5.2 mm in diameter and has a depth to diameter ratio of 0.5. The "Big Guy" crater was located on tray H03; experiment M0001, J. Adams, Principal Investigator. Although the experiment faced out into space, this particular impact occurred on an Al metal Z-frame, which projected in the ram direction (see photographs in ref. 1, p. 410-411). In addition, the impactor penetrated eight layers of lexan before encountering the Al surface. Our objective in examining this crater was to determine the nature and origin of the impactor. The crater was examined carefully for impactor residue or other evidence of the impactor's origin.

METHODOLOGY

The crater was first observed by a stereo microscope, then by field emission scanning electron microscopy (FESEM). Samples were then analyzed for impactor residue by energy dispersive spectroscopy (EDS) equipped with a light element detector, followed by cursory examination by time-of-flight/secondary ion mass spectroscopy (TOF-SIMS; see ref. 2 for instrumental technique).

The Hitachi FESEM is equipped with a light element detector, allowing for the analysis of boron, carbon, nitrogen, and oxygen by energy dispersive spectroscopy (EDS). However, this analysis can be complicated by contamination, which can be very significant if steps are not taken to minimize the effects. The contamination can arise from several sources including sample handling, preparation and contaminants in the electron column. Organic contaminants on the surface will result in polymerization around the electron beam if it is focussed, due to the heat generated in a small area and the electrostatic attraction of the beam. This effect is minimized both by careful handling and by rastering the beam over a several square micron area during analyses.

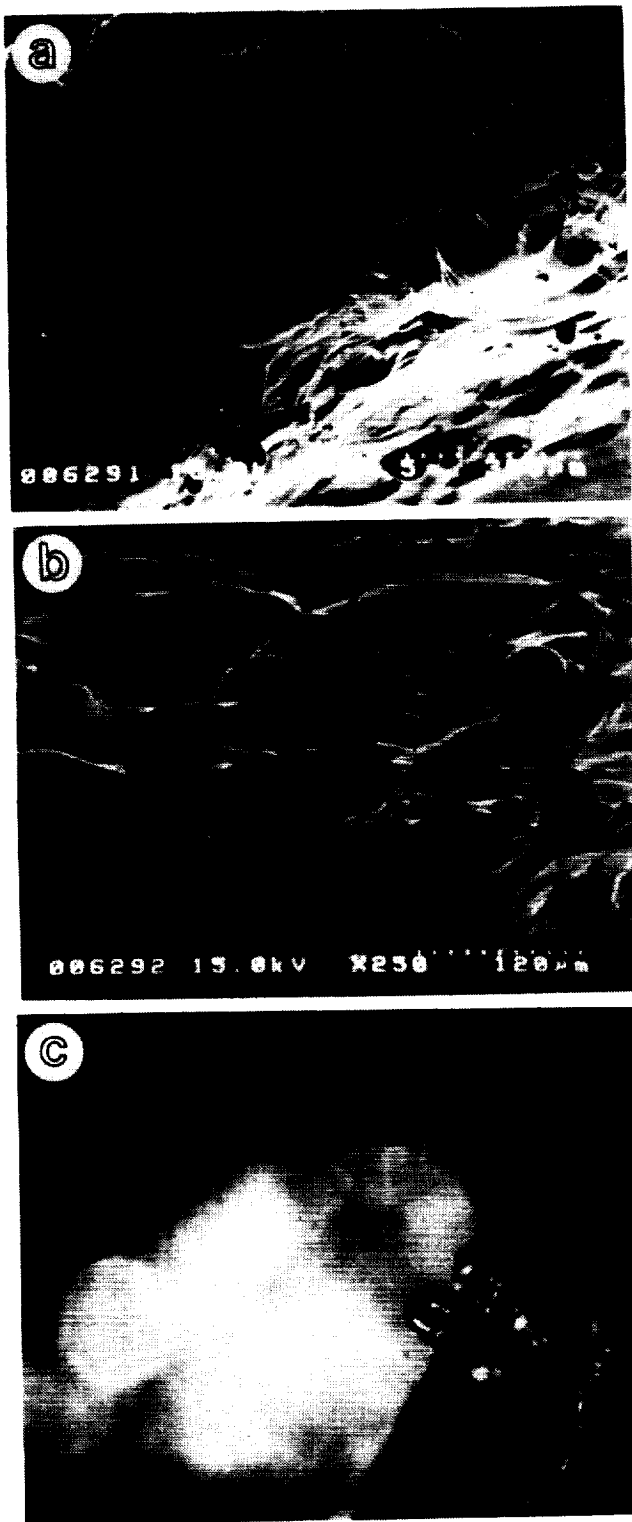
RESULTS

An FESEM image of the crater is shown in Fig. 1. A small amount of melt is visible in the crater bottom with more melt on the upper wall near the rim. In general, the melt liner appears to be quite thin. No intact projectile or dark patches on the rim were found. The only prominent melt-forms are droplet to dome-shaped columns (see Fig. 2). These objects on the rim appear to be darkened on their top surfaces when viewed through the stereo microscope, although this could also be an artifact due to illumination

under the microscope. Figure 3a shows an example of the unusual domed objects, with the horizontal layering effect. Figure 3b is an example of a melt form that appears to have collapsed before it completely froze.



Figure 1. FESEM imagery mosaic of the Big Guy crater.



FESEM-EDS analyses of the crater cavity and rim show the presence of Si, Mg, C, and O. The amounts of Si, in particular, vary considerably, depending on the location of the analysis. The top of droplets and dome-shaped columns have the highest amounts of Si, melt liners intermediate amounts and unmelted areas on the rim, the lowest (Fig. 4). The rim analysis also corresponds to an analysis of a point away from the crater that was covered with lexan before it was removed for the crater study. A piece of the frame underside was polished and analyzed by a Cameca electron microprobe. This analysis, and an additional analysis away from the crater in the vicinity of the EDS analysis, show the average Si content to be 0.34 wt % (range, 0.23 to 0.39) and Mg content is 0.94 (range, 0.83 to 1.02). Thus, the EDS spectrum of the point away from the crater is taken to be the background reference composition of uncratered Al. By comparing analyses of melt forms, Si shows an increased content of at least 3-fold or ≈ 1.0 wt %; Mg shows no significant change. The presence of C, intrinsic to the crater, is confirmed by EDS analyses, although some unknown amount is attributed to contamination during analysis. TOF-SIMS analyses indicate, in addition to Si, Mg, C, O, the presence of S, Cl and Na, which are known contaminants of LDEF surfaces.

Figure 2. FESEM images. (a) Top side of rim with a bulb-shaped melt form (arrow) with a broken stem. Lower portion of image looks down into the crater cavity. Note melt liner on the wall surface, but not the rim. (b) Droplet forms on the lower part of wall. Numbers refer to analyzed spots. (c) Domed column atop crater rim (sample tilted 45° for lighting purposes). Stereo photograph; column diameter = 0.08 mm.

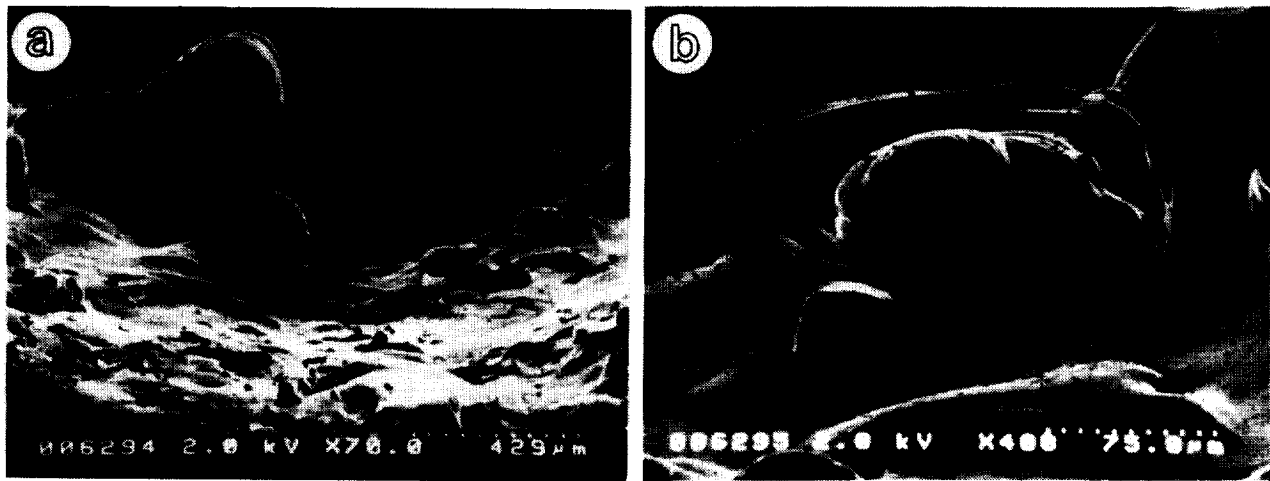


Figure 3. FESEM images. (a) Open arrow points to domed object with prominent rings/layers. Solid arrow indicates a melt droplet that collapsed into a "puddle" before solidifying. (b) Enlarged view of collapsed droplet.

DISCUSSION

Analyses of the crater show no chondritic compositional evidence (Si, Mg, Al, Ca, Fe, S, \pm Ni) for an extraterrestrial impactor. Silicon and Mg contents are attributed to the intrinsic minor element composition of the 6061 T6 Al plate. Silicon is enriched in the melt liner and melt forms relative to Al away from the crater. The mechanism for increasing Si content in the Al is unknown. Either an enrichment of intrinsic Si occurred during impact melting by some fractionation process or Si was added by an unknown orbital debris impactor. Carbon content is most likely a contaminant that resulted from vaporization of the overlying lexan during impact.

Silicon is added to Al to form a harder, somewhat less ductile alloy; enhanced Si content also increases the viscosity of molten Al (ref. 3). The peculiar layered textures of the melt forms may have resulted from differential cooling rates between the higher viscosity melt surface, which we find to be enriched in Si, and the underlying portions that may be less viscous. These textures may also have arisen, in part, from spiral dislocation arrays promoted by non-equilibrium and rapid cooling conditions. We conclude that compositional heterogeneities together with extremely rapid cooling (the crater forming event was very fast, on the order of 10 μ sec; ref. 4) probably gave rise to the unusual forms and textures observed in the Big Guy crater.

It is disappointing to note that the largest crater on LDEF was probably formed by collision with a piece of space junk. Dale Atkinson (pers. comm., 1993) analyzed the orientation of the crater on LDEF and concluded from orbital considerations that the impactor debris could have come from a Vandenberg Air Force Base launch.

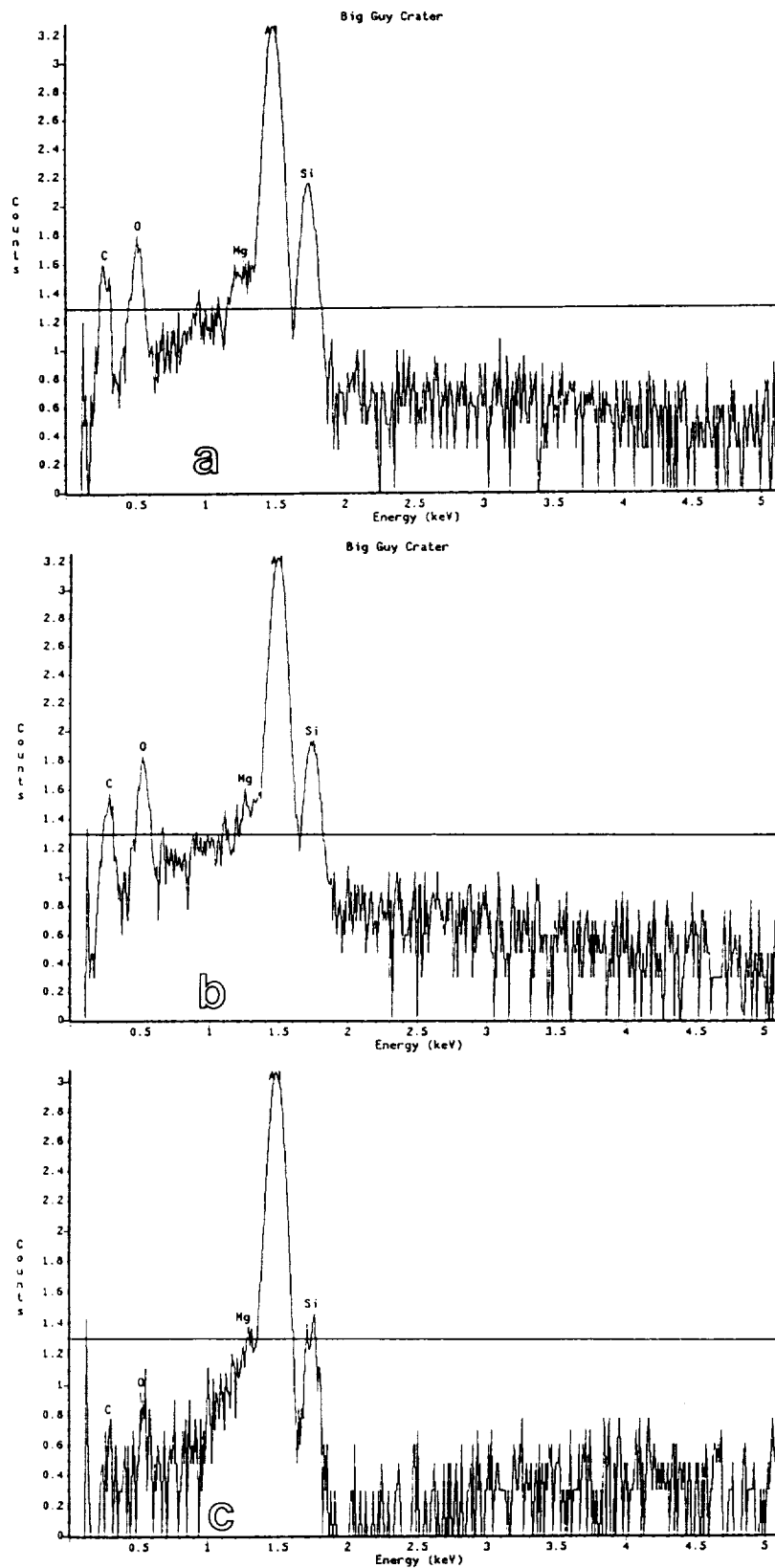


Figure 4. EDS analyses of droplet top (a), domed columns (b), and melt liner (c). Horizontal line in each indicates intrinsic Si content of Al alloy. The y-axis (counts) uses a logarithmic scale to allow examination of minor elements in the presence of Al.

ACKNOWLEDGEMENTS

We thank Jim Adams for the loan of the Big Guy crater and J. Erlichman for technical assistance.

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