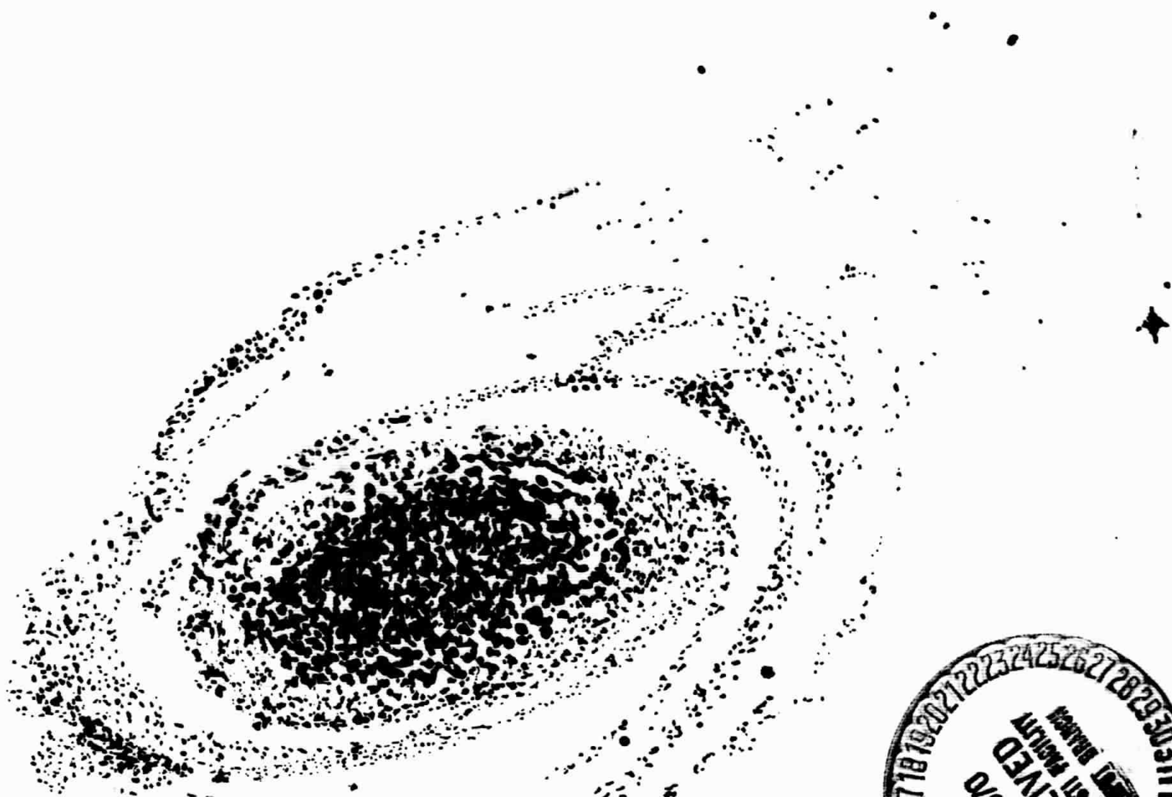
SURFACES FOR MICROMETEOROID IMPACT CRATER DETECTION

D. E. BROWNLEE and P. W. HODGE



Smithsonian Astrophysical Observatory
SPECIAL REPORT 308

Research in Space Science
SAO Special Report No. 308

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February 20, 1970

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

Because of the importance of increasing the sensitivity of micrometeoroid-detection experiments, a Van de Graaff microparticle accelerator was used to investigate the general properties of micron-sized impact craters in various surface types. Of the 22 surfaces studied, glass, Au film on lucite, and Al film on glass were found highly efficient in displaying impacts and could be used for statistically meaningful determinations of flux and species in spite of the low particle flux implied by many recent rocket and satellite measurements.

RÉSUMÉ

Il est important d'augmenter la sensitivité des expériences de détection des micrométéorites, c'est pourquoi nous avons employé un accélérateur Van de Graaff à microparticules pour étudier les propriétés générales des cratères d'impact de la taille du micron dans différents genres de surfaces. Parmi les 22 surfaces étudiées, le verre, les films d'or sur support en lucite, les films d'aluminium sur support en verre furent trouvés très adequats pour montrer les impacts et on a pu les utiliser pour des déterminations de flux et d'espèces ayant une signification statistique, en dépit du faible flux de particules mis en jeu par plusieurs mesures récentes faites par fusées et satellites.

КОНСПЕКТ

В связи с важностью увеличения чувствительности опытов по обнаружению микрометеорных тел, употреблялся ускоритель микрочастиц Ван де Графф, для исследования общих свойств ударных кратеров микронных размеров в различных образцах поверхностей. Из исследованных 22 поверхностей, стекло, пленка Au на пластмассе люсайт и пленка Al на стекле были найдены очень эффективными для показания ударов и могут быть применимы для статистически имеющих смысл определений потоков и разновидностей несмотря на низкий поток частиц подразумеваемый недавними измерениями сделанными с помощью ракет и спутников.

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1. INTRODUCTION

Attempts at in-space detection of micrometeoroids have historically been plagued with a wide range of errors and uncertainties. The technique probably least subject to uncertainties is that of recoverable crater-collection experiments such as those flown on Gemini 9, 10, and 12 (Hemenway, Hallgren, Coon, and Bourdillon, 1968). In this type of experiment, surfaces are exposed in space, recovered, and scanned microscopically for high-velocity impact craters. If proper surface materials are chosen, impact sites of high-velocity particles (meteoroids) can readily be distinguished from surface defects and particulate contamination. After measurement of the spatial density of craters and on the basis of a series of assumptions common to all detection systems, an omnidirectional flux of particles can be determined (Bandermann, 1967). For some craters, the chemical composition of the micrometeoroid can also be determined by microprobe analysis of particle residue in the crater (Auer, Grun, Rauser, Rudolph, and Sitte, 1968).

Most of the crater-collection attempts flown successfully to date have not yielded positive results (Brownlee, Hodge, and Wright, 1969; Weihrauch, Gerloff, and Fechtig, 1968; Ferry, Farlow, and Blanchard, 1968; Farlow, Blanchard, and Ferry, 1968) because their time — area products were not large enough. Assuming the flux measurements by the penetration detectors (OGO 3, Pegasus, Lunar Orbiter, and Explorer 16) are correct, then a crater-collection rate can be expected to be roughly $0.01/cm^2/day$ for craters $3\,\mu$ and larger.

This research was largely supported by NASA grant NGR 48-002-033 to the University of Washington.

For an exposure of 10 to 100 days, the spatial density of craters is then exceedingly small. With the added problem of particulate contamination from the spacecraft (Hallgren and Hemenway, 1968; Brownlee et al., 1969; Newkirk, 1967), the problem of reliable microscopic location of small craters becomes extremely difficult for many types of surface materials.

Consequently, for crater-collection experiments to be successful, special surfaces are required. Desirable surfaces are those that display impact phenomena in such a way that they can be rapidly located at relatively low scanning powers and can be positively distinguished from surface defects, particulate matter, and miscellaneous artifacts (i.e., the pseudocraters described by Weihrauch et al., 1968).

2. THE EXPERIMENT

In order to develop such surfaces, a cratering experiment was conducted in the space-simulation facility at the NASA Ames Research Center (Cunningham and Eddy, 1966). The experiment consisted of a matrix of 22 different surfaces, which were exposed to a beam of carbonyl iron spheres having a range in size of 0.5 to 2.5 μ and a velocity of ≈ 7 km/sec. The craters produced ranged in size up to 7 μ in diameter, with the majority being between 3 and 4 μ. The main purpose of the experiment was to observe the different types of effects possible on various surfaces, with the goal of providing guidelines for the construction of surfaces to be flown on future crater-collection attempts.

Final preparation of the surfaces was done in a class 100 laminar flow clean room. The thin metallic films were produced by vacuum evaporation in an oil-free vacuum system at 10^{-5} torr or lower. The nitrocellulose films were produced by the standard water-casting method.

After exposure, the surfaces were investigated with a scanning electron microscope and a wide variety of optical microscopes. The following descriptions of the optical appearance of the craters under routine scanning conditions are based primarily on observations with a Leitz Ortholux using combinations of upper and lower bright-field illumination.

3. OPTICAL APPEARANCE OF CRATERS IN SELECTED SURFACES

The following characteristics are only for the actual surfaces of the experiment and are not necessarily valid for similar surfaces produced with slightly different techniques or under slightly different conditions. The descriptions indicate what is seen under normal scanning techniques used for detecting craters in surfaces exposed in space. Various details are illustrated in Figures 1 to 5.

Glass

With upper illumination, large craters ($> 5\ \mu$) can be spotted as dark rings with dark central spots. Some craters show fracturing out to 3 to 4 crater radii. Small craters are difficult to identify but usually can be at 500 × on the basis of rim structure and minor fractures in the glass. With lower illumination, crater location is much more difficult because of reduced light reflection of fractures. No appreciable stress patterns were observed around the craters when observed through crossed polars.

Lucite

The craters are seen as dark rings with dark central spots. Some craters show short radial crack-like lines emanating from the crater edge but no apparent fracturing as seen in glass. Small craters are very difficult to locate and most craters are hard to identify positively. As with the glass, no apparent stress patterns around the crater were seen with crossed polars.

Solid Metallic Surfaces

Craters appear as dark rings with ragged edges and bright central spots. Some large craters can be spotted at 100 × but must be observed at 500 × or more for good identification. Small craters ($< 4\ \mu$) are difficult to find and sometimes cannot be positively identified at any power.

Thick Aluminum (> 1000 Å) on Glass

The craters are seen as dark ragged round holes sometimes surrounded with a mount-like structure producing an optical halo effect around the crater. Some craters show fractures in the film out to about 3 crater radii. Small craters that do not produce effects in the surrounding aluminum can be located using lower illumination but are difficult to identify. (A special technique for verification of high-velocity impact on aluminized glass is described in Secretan and Berg, 1969.)

Medium Aluminum (≈ 500 Å) on Glass

The craters appear as dark spots that are surrounded by an area of clear glass terminated by curled pieces of aluminum. The clear-glass area is always circular and symmetric about the crater and usually is about 6 crater radii across. All the craters seem to show this symmetrical peeling effect, which effectively amplifies the optically identifiable image of the impact site by a factor of 4 over craters in conventional solid surfaces. All craters larger than 2 μ can be spotted and identified at 50 × to 100 × using upper and lower illumination.

Thick Aluminum (> 1000 Å) on Lucite

Most of the craters can be seen at 500 × as volcano-type structures. A few of the larger craters have radial cracks and some peeling or cracking of the film. In general, craters are hard to locate and identify.

Thin Aluminum (≈ 100 Å) on Lucite

The craters are surrounded with small irregular clear areas of lucite terminated with peeled aluminum. The craters are harder to find than those in thick aluminum on lucite, but easier to identify because of the peeled film.

Gold Film (≈ 1000 Å) on Lucite

The craters appear as dark spots with fine radial streamers extending from the crater rim for about 1 crater radii. For all craters larger than 2 μ, the impact site is surrounded by a large area of clear lucite terminated by curled gold film. The clear areas are usually highly irregular, with tearing often preferentially along scratch lines in the lucite. The image amplification effect caused by the peeling is sometimes as large as 50, and all craters > 2 μ can be very easily spotted at 50× or 100×. With lower illumination, most of the craters can be spotted with the naked eye.

Aluminum-Coated Thin Plastic Films

Craters that penetrate the films are almost impossible to identify. Most of the holes are merely clean holes and are too easily confused with film defects for safe identification.

Gold Film (≈ 1000 Å) on Glass

With upper illumination, the craters are seen as bright rings (crater rim) with dark centers. There is neither film peeling nor cracking, but apparently the film is lifted above the glass to form a mound because the craters appear to be surrounded by a faint optical halo. Many of the craters can be spotted at 100× because of their halo, but positive identification is sometimes questionable.

The above effects are not necessarily exactly what would be observed if the surfaces had been exposed in space. The effects of incidence angle, wider velocity range, and particle type are not well understood, but the experimental conditions were at least a reasonable approximation to an actual space exposure. The effects of space environment, other than vacuum, were not included because of the wide range of environments possible on different types of space experiments.

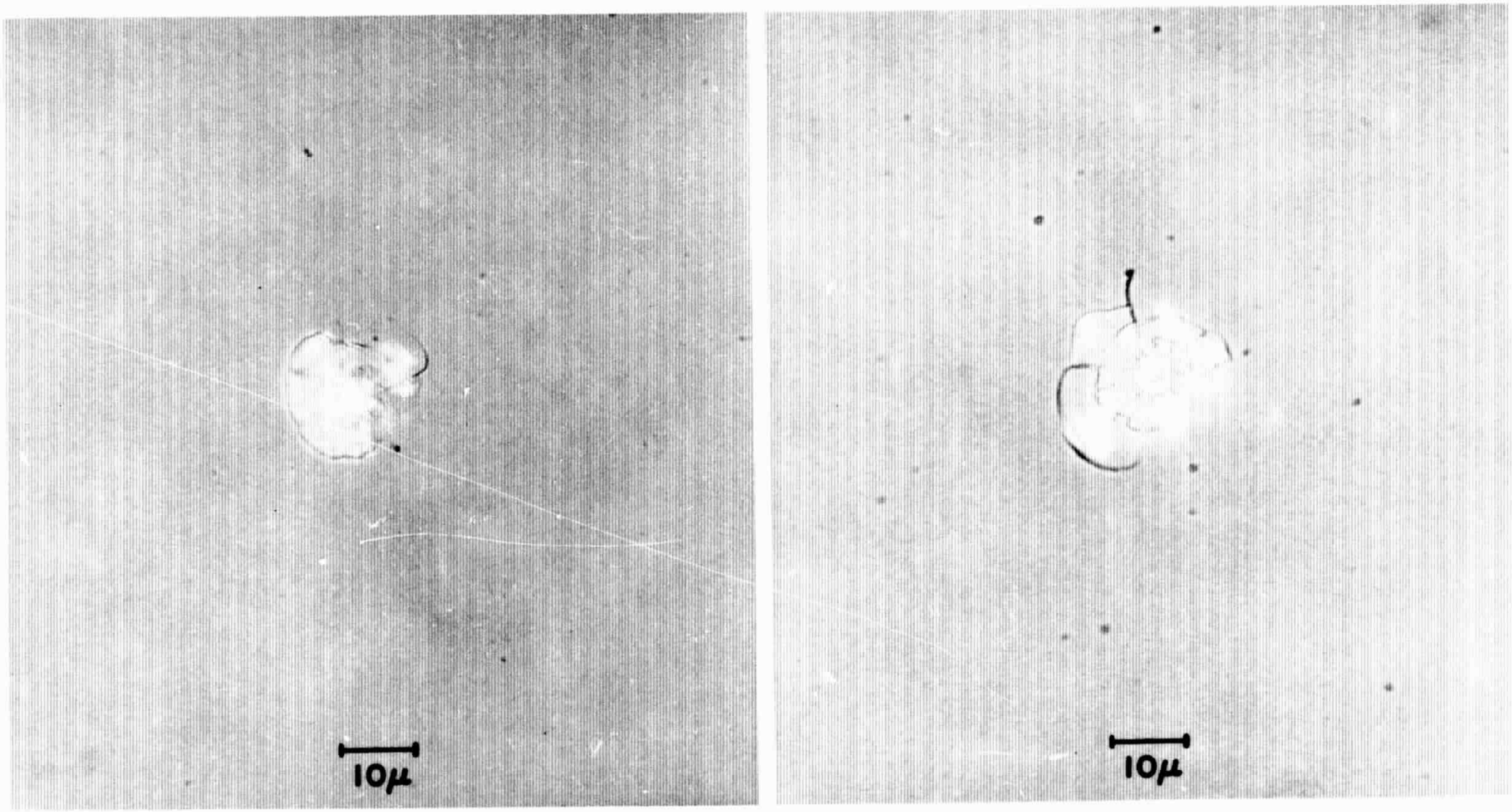

Figure 1. A 4- and a 5-μ crater in glass, showing large-scale shattering.

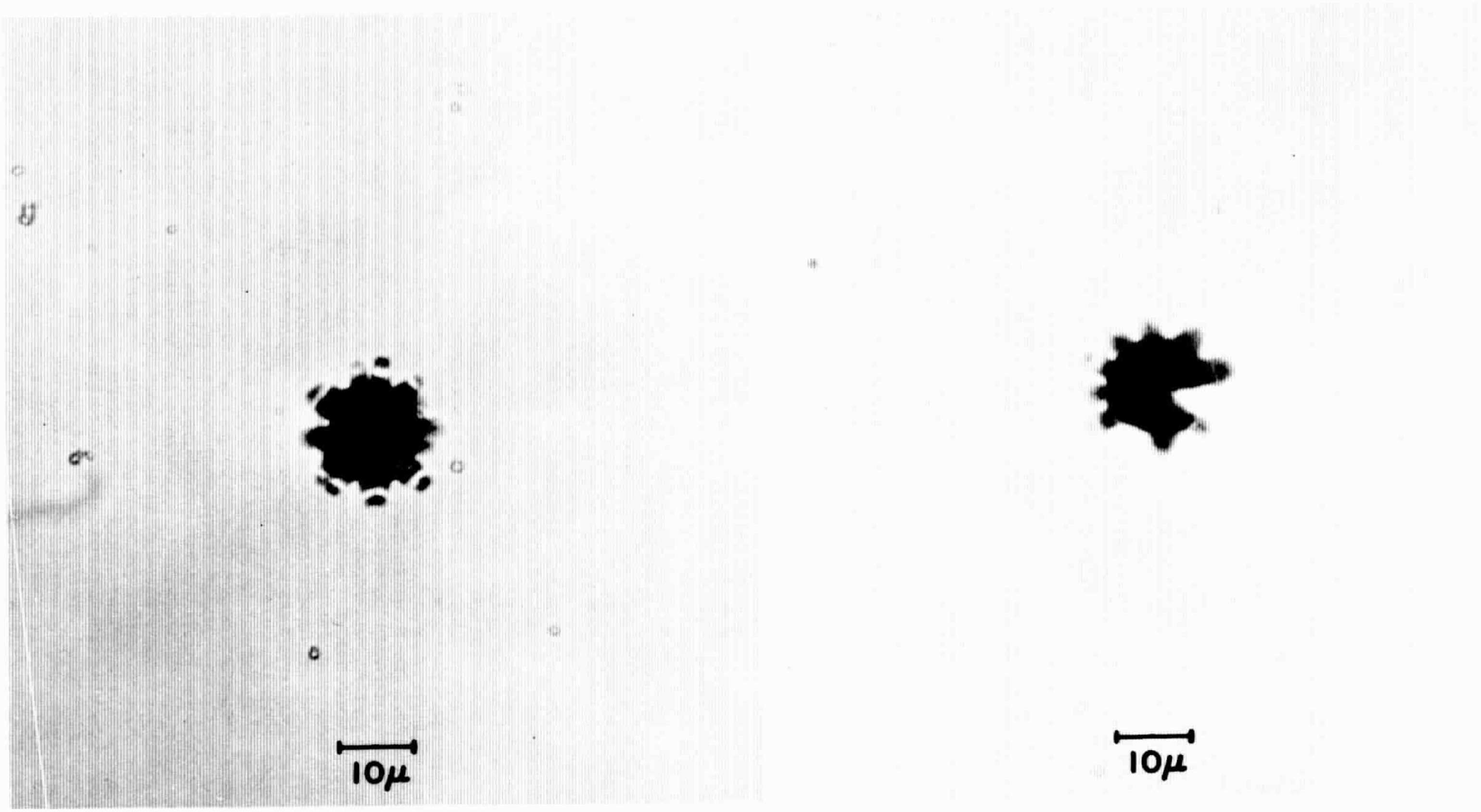

Figure 2. Two 5-μ craters in medium Al/glass, showing the symmetrical film peeling.

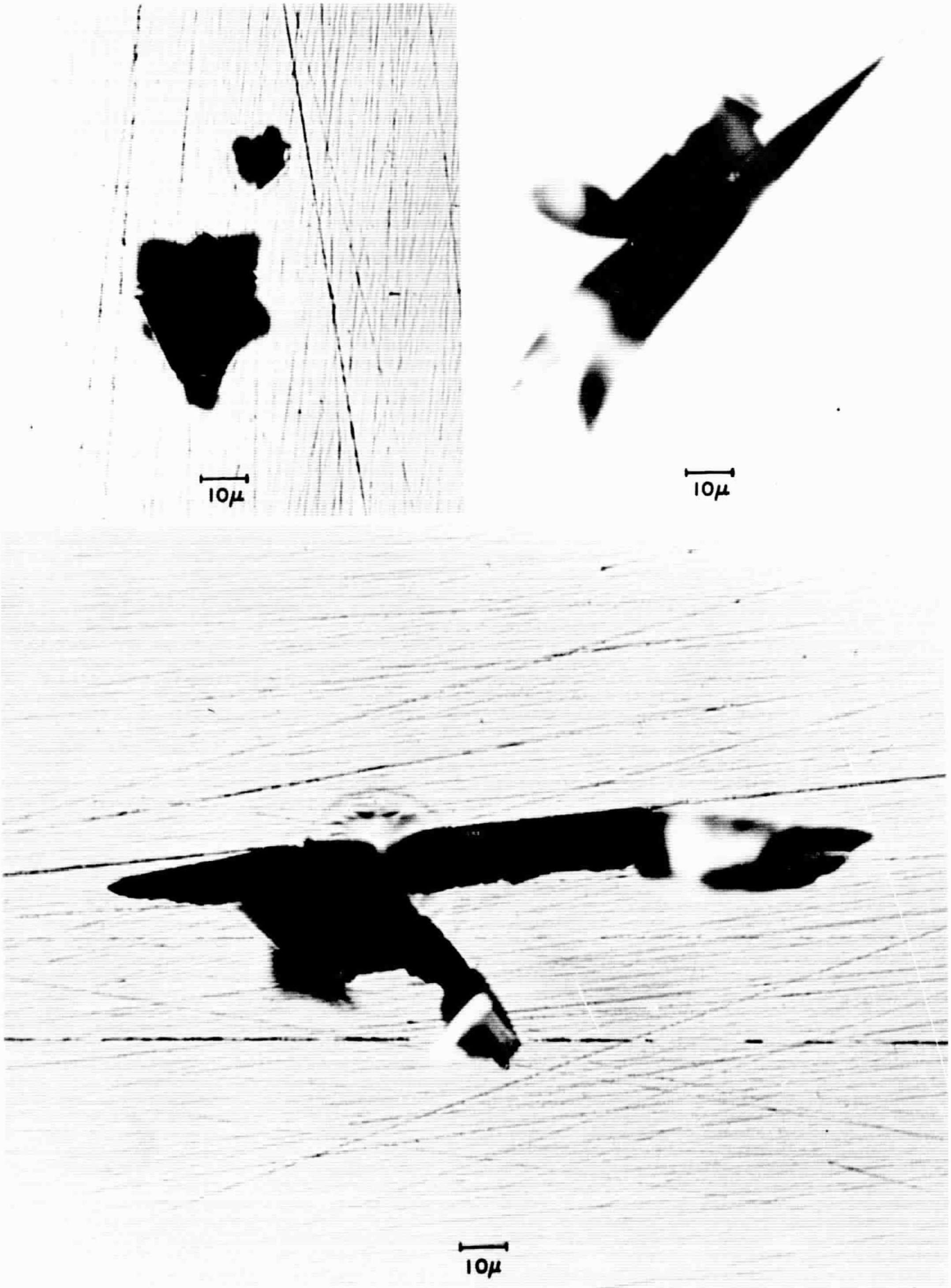

Figure 3. Craters 3 to 4 μ in Au/lucite, showing film peeling.

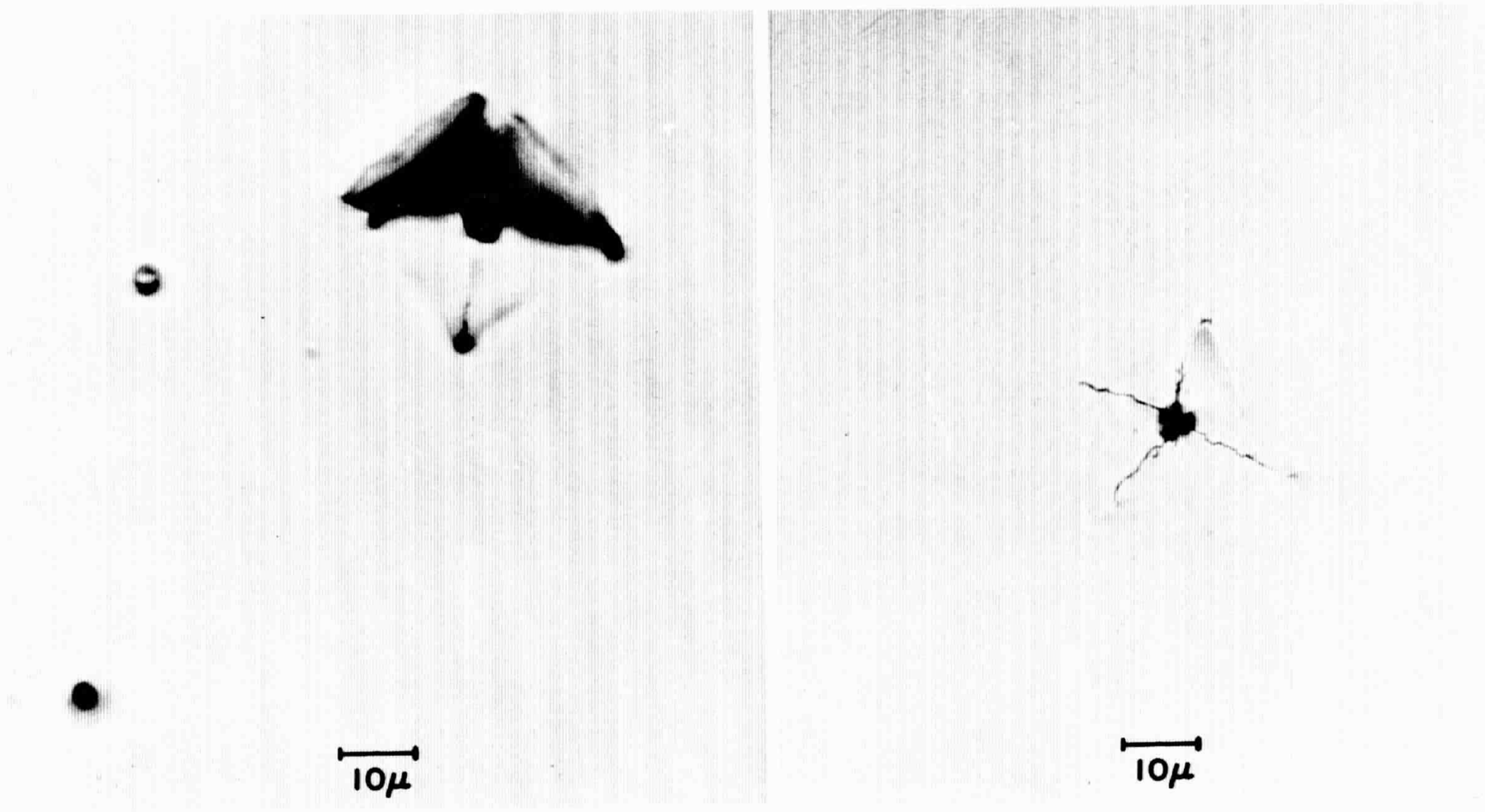

Figure 4. Three craters (2, 3, and 4 μ) in thick Al /lucite and one crater in thick Al/glass.

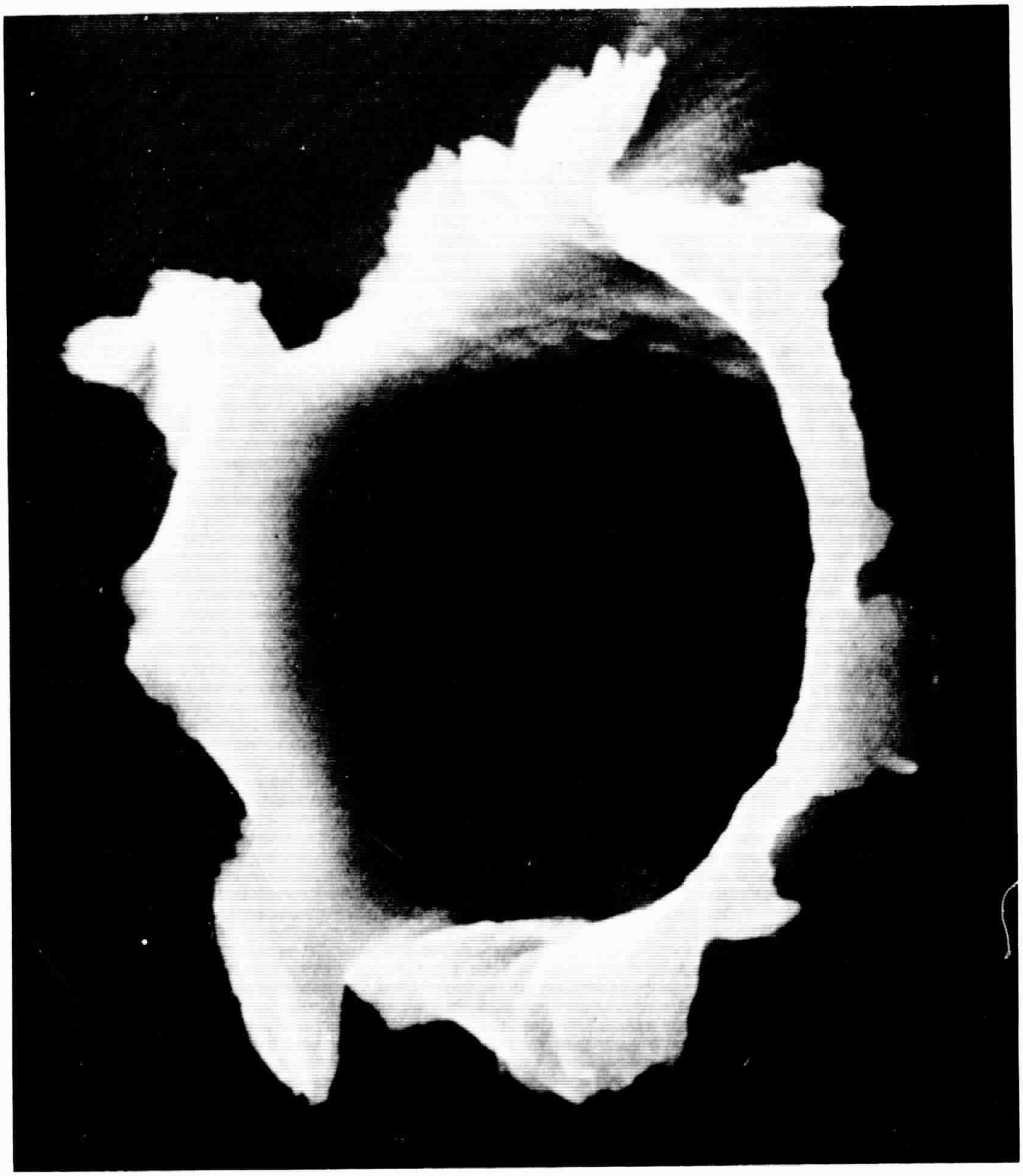

Figure 5. A scanning electron micrograph of a 5-μ crater in stainless steel.

4. RESULTS

As a result of the experiment, two effects were found that greatly reduce microscope time required for reliable location and identification of impact sites. These effects are fracturing around craters in glass and metallic film peeling. The large-scale fracturing effects were found only for large craters and could probably be used reliably for surveys of craters 10 μ and larger. There is possible confusion with various types of glass defects (Calbrick, 1962), but the hypervelocity shattering is fairly characteristic and not easily confused with normal defects. If there is serious question about a crater, it can be inspected in a scanning electron microscope, where the fracturing around the crater and melting in the crater provide absolute identification.

The peeling effects of certain opaque metal films on transparent bases provide the most attractive surface criteria for crater location. When the film peels away from the crater, large holes are formed that can very quickly be located with low-power and lower bright-field illumination. There is also no confusion with other surface objects or defects. In the experiment, pronounced peeling was observed only on the Au/lucite and the medium Al/glass and not on the other slides. (Film peeling has also been observed in macroscale cratering (McMillan, 1963).) The peeling probably depends on thickness of the film, the film material, the bonding strength to the substrate, and the energy in the cratering process. On the two slides mentioned, the effect was noted for all craters 2 μ and larger. The film thickness is important, as shown by the experiment, and apparently there is an optimum thickness for maximum effect. The fact that gold peeled much more than the aluminum suggests that the film-substrate bond is important. This bond is dependent on the film and substrate materials and also on the deposition rate, substrate temperature, surface contamination, etc. Mechanical properties of thin films are highly complex (Hoffman, 1964), and reproduction of exact properties from one batch of surfaces to another is very difficult. Therefore, each batch of surfaces to be flown on a crater-collection experiment probably requires calibration by placement in a microparticle accelerator.

5. CONCLUSION

On the basis of the results of the experiment, it seems quite possible to make meaningful crater collections from spacecraft. For example, 1 m^2 of Au/lucite exposed for a period of 2 months would have approximately 5000 optically detectable craters. The craters could be found in spite of gross contamination, and the estimated optical scanning time for location of the craters would be on the order of a few man-months. With proper sizing and microprobe analysis of the craters, invaluable and fairly absolute data could be obtained on both flux and characteristics of the zodiacal-cloud particles at 1 a. u.

6. ACKNOWLEDGMENTS

We are grateful to Bernard Cunningham and his staff at Ames Research Center for running the experiment in their microparticle accelerator and to Steven Pinson and his staff at the JEOLCO Applications Laboratory in Burlingame, California, for the use of their scanning electron microscope. We are also indebted to William Bucher for preparation of the cratering surfaces and to F. W. Wright for many helpful discussions.

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BIOGRAPHICAL NOTES

DONALD E. BROWNLEE received the B.S. degree from the University of California at Berkeley in 1965 and is currently a candidate for the Ph.D. degree from the University of Washington.

His thesis is a study of interplanetary dust by direct sampling.

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