DISTINGUISHING BETWEEN OBLIQUE INCIDENCE AND NON-SPHERICAL PROJECTILE IMPACTS

Lucinda Berthoud, *MMS Ltd, Filton, PO Box 16, Bristol BS12 7YB, GB*
Jean-Claude Mandeville, *ONERA-CERT, 2 Ave. Ed. Belin, 31400 Toulouse, France*

ABSTRACT

Two series of experiments were performed to investigate the distinguishing features between craters caused by oblique incidence and those caused by non-spherical particles. The first series of experiments used the MPI Heidelberg electrostatic accelerator to accelerate micron-sized iron spheres on to aluminum targets at a constant velocity and increasing angles. The second series of experiments were performed using a light gas gun to fire non-spherical and spherical glass projectiles onto aluminum targets at similar velocities. Comparison of the two experiments showed that craters formed by the fragments showed a different morphology to those created by oblique impacts.

1. INTRODUCTION

In the past few years a wide variety of surfaces have been brought back to Earth after being exposed to the space particulate environment. The impact features found on these surfaces can give clues to the characteristics of the orbital debris and meteoroids that created them. Many investigations have been carried out to deduce particle parameters (size, shape, impact angle) from the morphology of impact features. However, there are still some ambiguities in the interpretation of these morphologies. In this study we have examined the distinguishing features between craters caused by oblique incidence and those caused by non-spherical particles. The experiments were also intended to constrain the critical angle of incidence that causes oblique incidence craters to be morphologically different to normal incidence crater and to establish whether we can differentiate a crater caused by a spherical impactor from one caused by a non-spherical impactor. All experiments were limited in velocity to 5-6 km/s.

2. IMPACT ANGLE EXPERIMENTS

The aim of this series of experiments was to investigate the change in crater morphology for increasing angles of incidence. Although the recent work of Christiansen (Ref.1), McDonnell (Ref.2) and Watts (Ref.3) have gone some way to examine the detailed effects of impact angle and particle shape on crater morphology, these have not yet been investigated in a systematic way. The diameter of the crater is considered to be non-circular if its semi-major and semi-minor axes differ by more than 10% (i.e. above experimental error margins).

2.1 Experimental Conditions:

Equipment:	Electrostatic accelerator (MPI)
Projectiles:	0.7 µm diameter Fe spheres
Targets:	50 µm Al (99% pure) foils (effectively semi-infinite)
Velocity:	5.5 km/s
Angle:	0°, 30°, 45°, 60°, 70°, 80° to the normal to the target surface

Fig. 1 shows the mounting designed specifically for these experiments.

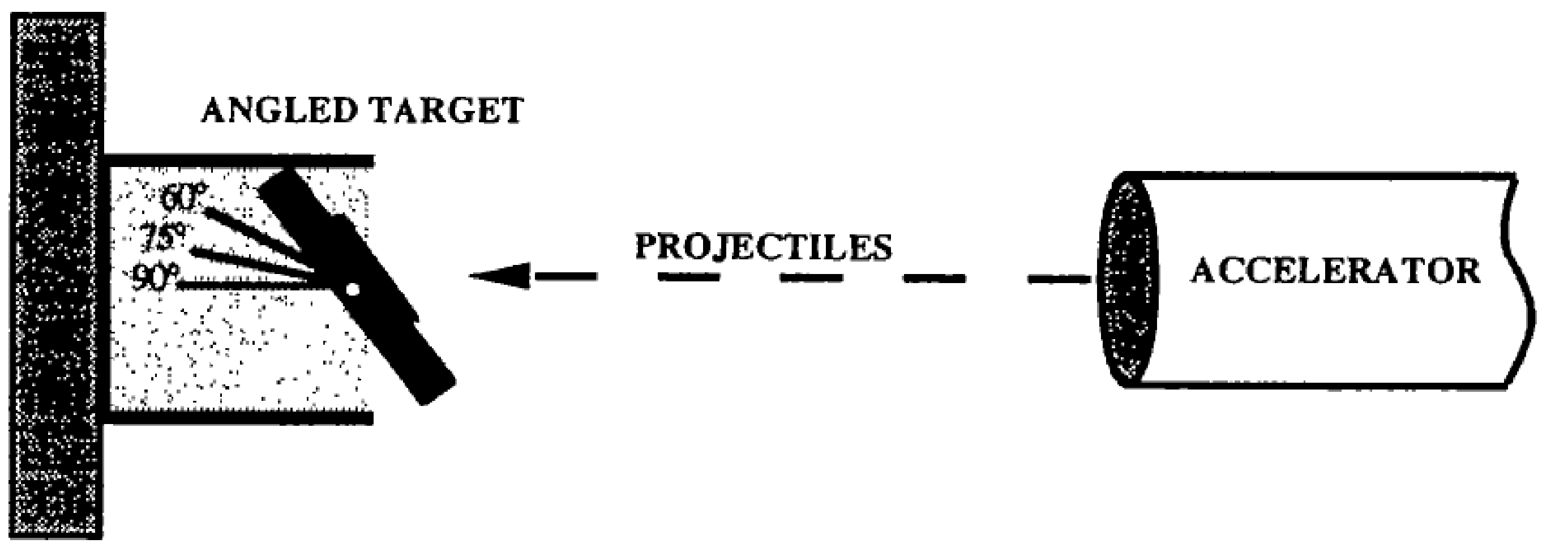

Figure 1: mounting for oblique impact shots using electrostatic accelerator

2.2 Results:

Fig. 2 shows typical impacts for each angle. In each image the impact direction is from the left. The progression from a circular crater (α = 0°) through slightly elliptical (α = 30°) to obviously elliptical (α = 60°) was seen. The critical α for which an elliptical crater is formed is : $0° < \alpha < 30°$. The beginning of a shelf formation on the 'exit' side of the crater was noticed for α = 60°. With increasing impact angle the crater becomes more and more elongated, eventually leading to a decapitation (or ricochet) effect at α = 80°. From EDX analysis of the different parts of the crater, the second crater of a ricochet appeared to be caused by the impact of part the projectile, and not by part of the target. The second craters were not always smaller than the first ones.

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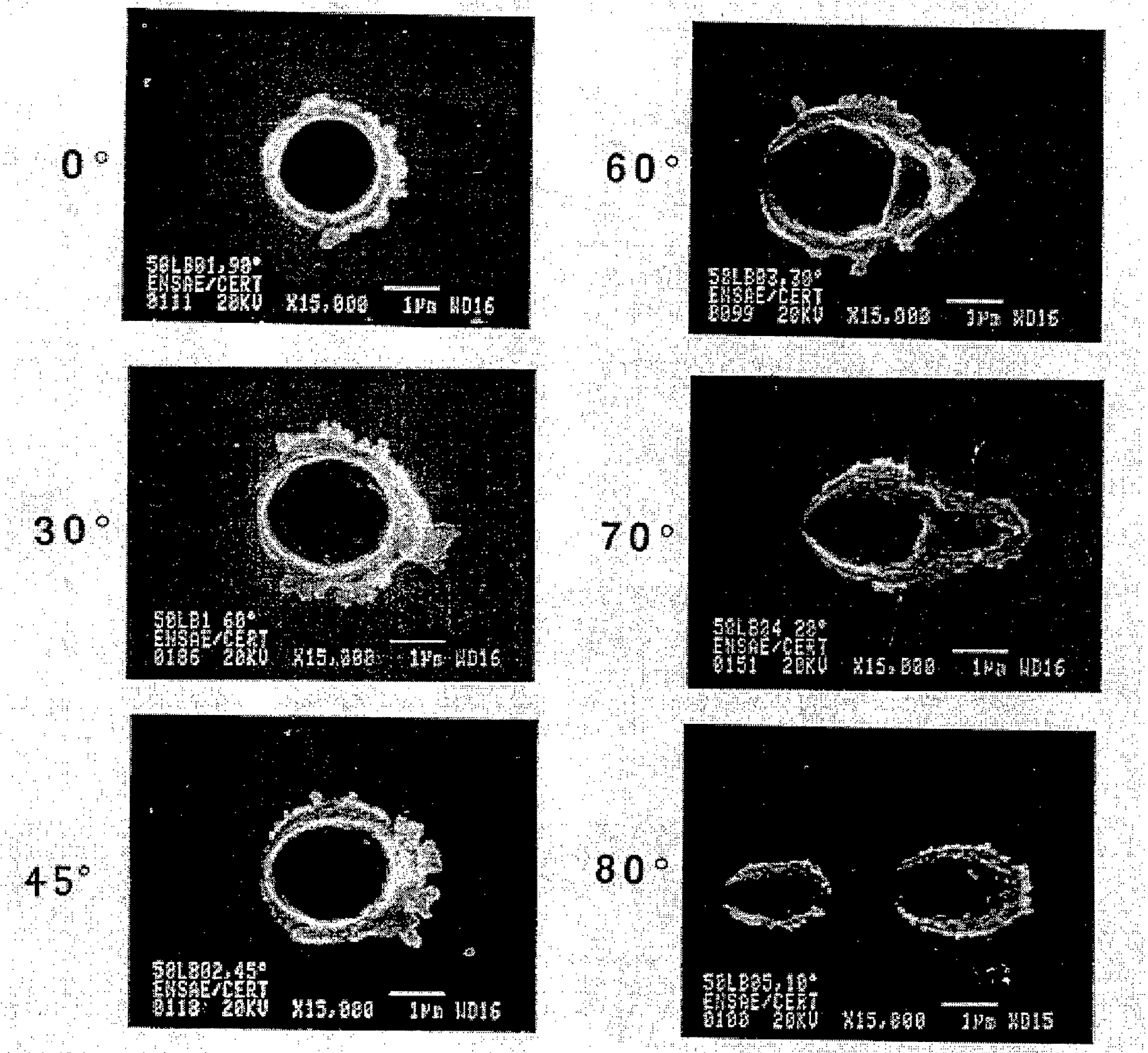

Figure 2: Oblique craters in aluminium for increasing impact angle.

3. INFLUENCE OF PARTICLE SHAPE

The detailed influence of particle shape on crater morphology (the relief of crater bottom and lips) and geometry (depth/diameter ratio and circularity of impacts) has not been examined. The experiments described here were carried out using two different shapes of projectile of nominally the same size: glass spheres and glass fragments.

3.1 Experimental conditions

Six impacts using spheres and seven using fragments were produced.

Equipment: Light gas gun (NASA JSC) and SEM-EDX chemical analysis
Projectiles: Soda lime glass spheres or fragments of nominal 150 μm diameter
Targets: 2 mm thick 6061-T6 aluminium
Velocity: 6 km/s

The difference in projectile shape is illustrated by Fig. 3. The fragments were created by grinding and sized by sieving. Their length to diameter ratio varies from 1 to 5, with an average of 2. Soda lime glass contains SiO_2, K_2O, Na_2O and CaO. The volatile/refractory nature of these oxides could give clues to the vapour-fractionation processes during impact.

3.2 Geometry Results

Crater depth over diameter (P/D) can be measured directly from the craters:
The mean P/D for the craters made by spheres = 0.55 with standard deviation = 0.043
The mean P/D for the craters made by fragments = 0.65 with standard deviation = 0.063

The fragments consistently create deeper impacts than spheres. Therefore future P/D interpretations from craters on space-exposed surfaces should take this into account.

The circularity (Ci) of the craters was also measured, it was defined as:

$$Ci = \frac{\Pi b^2}{\Pi ab} = b/a$$

where 2a is the semi-major axis, and 2b is the semi-minor axis. The circularity of the craters from spherical impactors varied from 0.95 to 1 (almost perfectly circular), whereas the circularity of the fragment craters varied from 0.82 to 1.

3.3 Morphology Results

The circularity of the craters is clearly influenced by the shape of the projectile. The craters produced vary from elliptical and shallow (if fragment strikes sideways on) to circular and deep (if fragment strikes end on). Crater dimensions therefore depend strongly on the position of the projectile upon impact.

The craters created by spheres show considerable symmetry and uniformity in the crater bottom and lip thickness. The glass is in a melt form, pancaking over the bottom of the crater, then breaking up from the centre and 'walking' up the walls. For the craters created by fragments, the general morphology was highly irregular, although the lip thicknesses were fairly uniform. The crater bottoms showed shelves and pockets of different depths. The glass was also present as a melt, but in piecemeal fragmented form. The tiny droplets were often chaotically distributed in the crater bottom, sometimes indicating an off-centre point of impact. It is quite possible using the above features to differentiate between those craters created by spherical and non-spherical impactors using the above features.

3.4 EDX Analysis Results

An EDX analysis was carried out for each impact to confirm that the crater was made by a glass projectile, and not by sabot or gun debris. EDX analysis of the glass melt in the resulting sphere craters revealed a strong presence of Al, Si, O, Na, Ca and some Mg. No K was detected, although this was not surprising as K is the most volatile component of the glass. EDX analyses of the fragment craters indicated a strong presence of Al, Si, O and Na, but significantly less Ca and Mg than for the sphere craters, and again no K was found. These results are consistent with the relative volatility of the various elements. They imply that higher temperatures and pressures were reached during the impact of the fragment impactors.

4. COMPARISON OF EXPERIMENTS

When comparing the results of the experiments, we have to take into account the fact that they were performed with projectiles of different size. Comparing micron-sized craters with those hundreds of microns in size is not straightforward, even with the aid of a scanning electron microscope. However, we can see that the geometry of the craters created by normal incidence spherical projectiles have similar geometry in both cases. The next task is then to assess whether the oblique craters can be differentiated from the fragment craters. Note that the formation of the lip can be helpful in this: the fragment craters have random or symmetrical lip formations, whilst the oblique craters always have a more developed lip on the far side to the incoming projectile. Another distinguishing feature is the position of pockets: for the fragment craters, these pockets may form at a random position within the crater, whereas for the oblique craters the pocket or step always forms on the fars side to the incoming projectile. Using these two features, the lip and any pockets, we believe it is possible to distinguish between fragment and oblique craters.

However, it may be difficult to differentiate craters caused by fragment-like particles, from those caused by heterogeneous impactors. Pocket-like structures, which may have been caused by differential melting and vapourisation of different particle components, are very similar to the craters caused by fragments.

Velocity may also play a role: it is possible that above a certain velocity, particle shape no longer affects crater shape. This would explain the rarity on space-exposed surfaces of irregular craters not obviously due to oblique impacts. However, this is difficult to test, due to the lack of suitable facilities for accelerating irregular projectiles over 7-8 km/s.

5. FUTURE WORK

Two clear lines for future work are apparent from the last discussion: firstly, it would be useful to perform tests in the laboratory with heterogeneous projectiles in order to investigate the morphology of the resulting craters. However, this might pose some practical problems as heterogeneous projectiles are likely to blow apart under acceleration pressures; secondly it would be useful to perform a series of shots investigating the effect of increasing velocity (above 7 km/s) upon crater geometries formed by both oblique incidence and non-spherical projectiles.

6. SUMMARY OF FINDINGS

1. Relief of the crater bottom gives clues to projectile shape: smooth and regular => spherical projectile, pocket-like features and irregular =>non-spherical.
2. Fragment-shaped projectiles produce wide variation in crater profile (elliptical/ shallow to circular/deep).
3. Craters from non-spheres are distinguished from oblique impact craters by their irregularity and by absence of the distinctive lip and shelf formations of the latter.
4. Further work needs to be carried out to investigate the effects of heterogeneous compositions and of velocity on crater geometry.

7. REFERENCES

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3. Watts A., Atkinson D. and Rieco S. "Dimensional scaling for impact cratering and perforation", report by POD Assoc.Ltd. 1993

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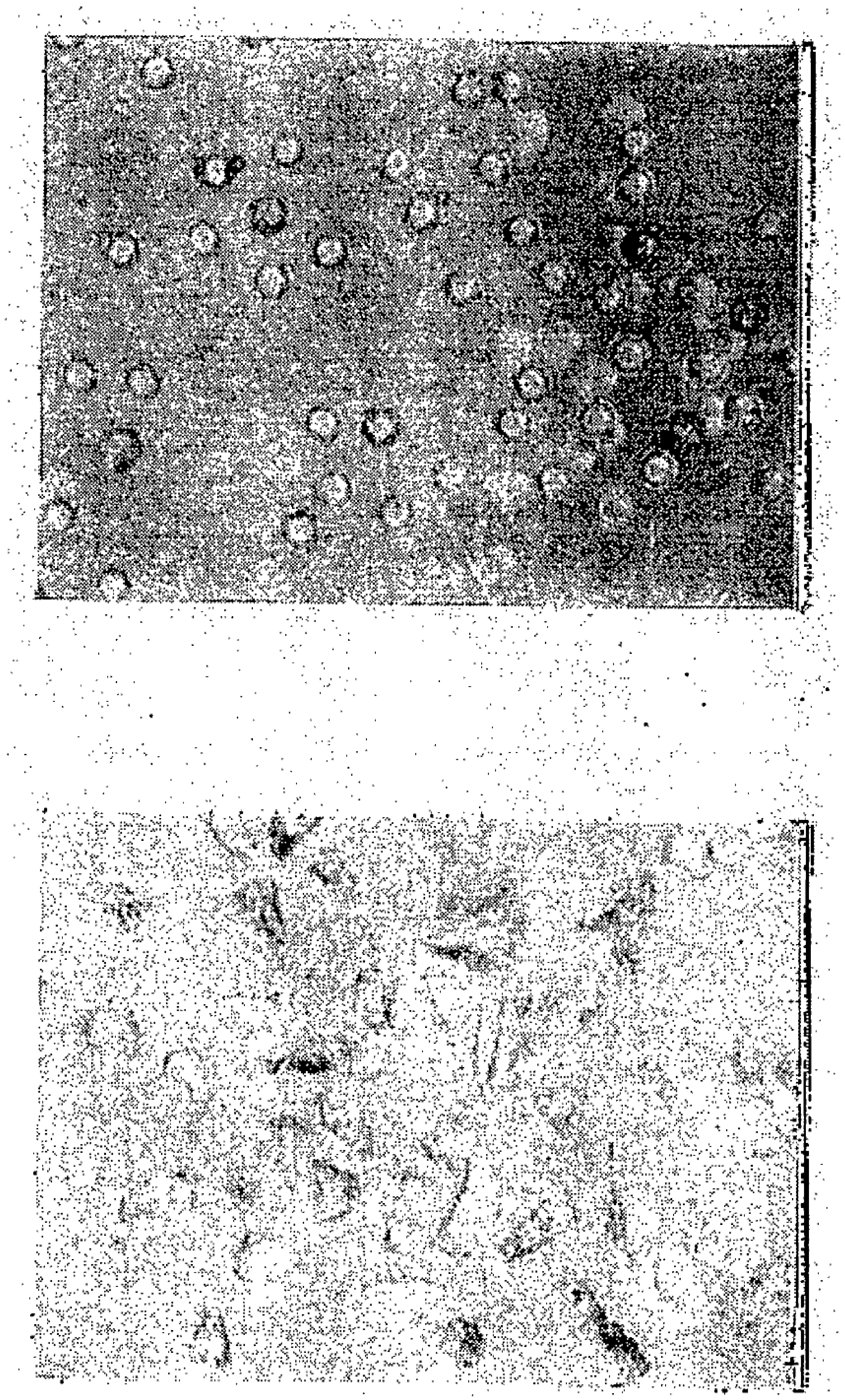

Figure 3: Soda lime glass spheres (diameter 150 µm) and fragments used as projectiles in particle shape simulation experiments (samples provided by NASA JSC)

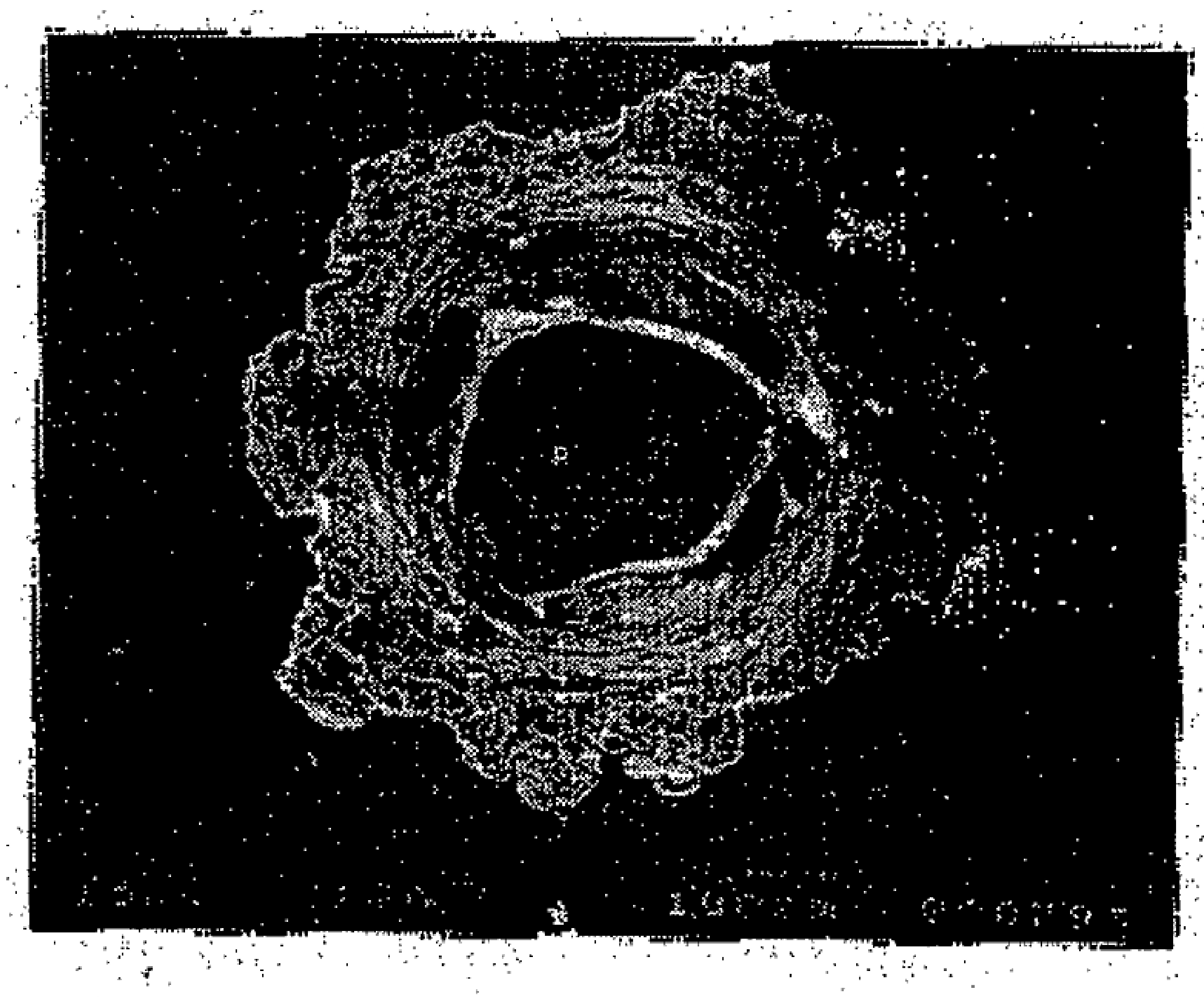

Figure 4: Crater from spherical projectile in aluminium target no. 1217B (Crater diameter D = 450 µm)

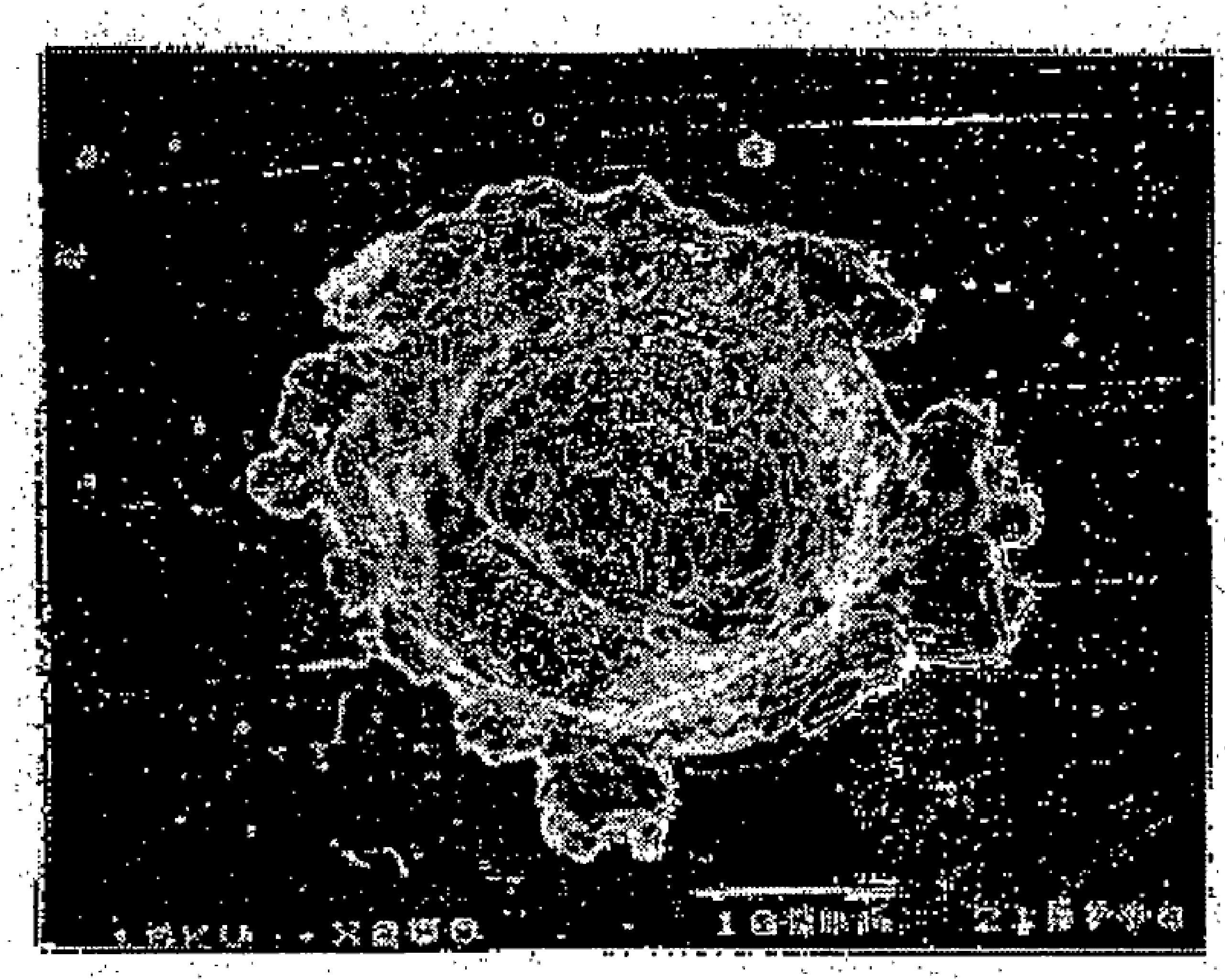

Figure 5: Crater from fragment projectile in aluminium target 1225B (D = 235 µm)

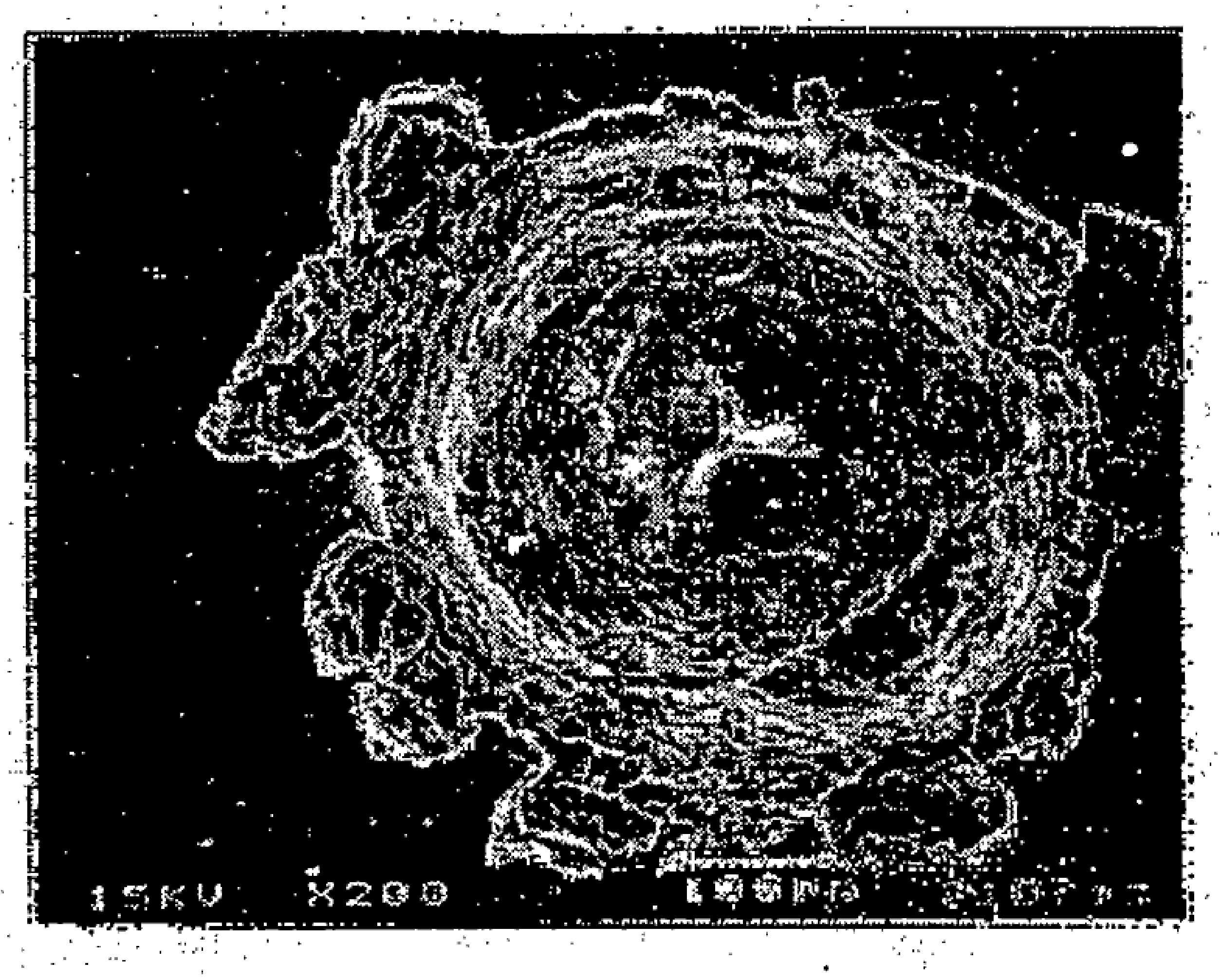

Figure 6: Elliptical crater 1225F in aluminium caused by fragment projectile (D = 300 x 225 µm)