No. 115 EXPLOSION CRATERS ON THE EARTH AND MOON

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ABSTRACT

A comparison of lunar craters with a particular set of similar-sized explosion craters on Earth leads to the inference that explosion craters on the Moon can be picked out with the aid of the following criteria: (*a*) relative altitude of rim crest and shape of outer rim profile, (*b*) slumping of inner rim materials, (*c*) nature and distribution of ejecta.

In 1944 ammunition stored underground near Fauld, England, exploded, producing a crater some 250 m in diameter. A few thousand secondary craters were produced in pastureland and wooded country around the main crater. The shapes of both the main crater and the secondaries, and their mutual spatial relations, find analogy with the shapes of certain craters on the Moon; and this led Baldwin (1963) to present a vertical air-photograph of the Fauld crater (Fig. 1) — which he referred to as the Burton-on-Trent Crater. Further information on the Fauld crater may be gleaned from (*a*) air and ground-based photographs taken in December 1944 by the R.A.F. shortly after the explosion, (*b*) an examination of the modified craters remaining in the field in 1967, and (*c*) Ministry of Defense documents relating to the nature of the explosion. Since the mechanism of formation of the Fauld crater is known, it is instructive to compare its morphology with that of similar sized craters recorded on the N.A.S.A. Lunar Orbiter Missions, with a view to determining which lunar craters are of explosive origin.

Prior to the Fauld explosion, an old alabastine mine with roads forming labyrinths approximately 200-400 feet deep in limestone had been utilised to store bombs and other explosive weapons of various weights. It was estimated that energy equivalent to 5.34×10^6 lbs. of TNT (about 4.54×10^5 calories) was liberated in the explosion. One may predict the size of the crater using Baldwin's (1963) relations with a scaled depth of burst $H/W^{1/3} \approx 1.7$, where H is the depth of the explosive centre in feet and W the energy released in pounds of TNT equivalent. Thus, had the explosive been centrally condensed, the blast would have given rise to a crater no larger than 200 m in diameter. The fact that the actual crater rim is ovoid (Fig. 2) and measures as much as 220 m x 270 m may be explained in terms of (*a*) the irregular distribution of stored charge, (*b*) the non-simultaneity of the explosion of individual bombs (many remained unexploded after the event), (*c*) the controlling effects of the pre-existing mine roads, especially from the standpoint of the shaping of the charge and of creating weaknesses in the country rock. The locations of a few of these roads may be traced across the floor of the crater in Fig. 2, especially when it is combined stereoscopically with Fig.

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2b

8. In spite of these factors, the ellipticity of the Fauld crater — 18.5% — measures an amount of distortion commonly found among the lunar craters, some of which have ellipticities (Fielder 1961*a*) that exceed 40%.

Field inspection and comparison of records with the early photographs showed that slumping occurred at most points around the rim of the Fauld crater immediately after the explosion. This produced a conspicuous bench (Figs. 4, 5, 6) some meters below the crest of the rim. Mass creep and water erosion have further modified the shape of the rim over the past 23 years (Fig. 7), and debris has covered the floor of the crater to an average depth of a metre or more in places. Under low lighting conditions the bench gives the crater a double-walled appearance similar to that of some small lunar craters (Fig. 8). The latter are usually sharp in outline, and are therefore relatively recent additions to the lunar surface; so it may be speculated that their double-walled appearance is due to slumping incident on an explosive origin.

The 70 m lunar crater in Fig. 8 is surrounded by numerous rocks that apparently have been tossed out of the crater during its formation. Better examples of ejected rocks around the rims of lunar craters 420 m and 30 m in diameter may be seen in Figs. 9 and 10, respectively. The lunar rocks may be compared with the large, angular blocks of limestone (Figs. 11, 12) which were torn from the principal Fauld crater and partially buried themselves or produced shallow depressions on impact with the soil or, again, with the smaller rocks ejected from one of the secondary craters at Fauld (Fig. 13). For the following reasons, this latter is believed to be an explosion crater.

Secondary craters produced by the impact of non-explosive materials range in diameter from 5 to 10% of the primary's diameter according to Fielder's (1961*b*) experiments with detonators, and from 4 to 11.5% according to Roberts (1964) measurements based on three high-explosive experiments and one thermo-nuclear explosion. By contrast, many of the secondary craters at Fauld exceed the upper limits of these ratios; in particular, one of the Fauld secondaries attains 20% of the diameter of the primary; and this indicates that many of these secondary craters were sculptured by the ejection of live bombs which exploded on impact. The tendency for some of the secondary craters to form linear arrays (see Fig. 1) may have arisen as a result of the particular disposition of the stacked bombs prior to their having been ejected.

Inspection of the shadows cast by the photographed secondary craters at Fauld leaves no doubt that many of them have rims that are raised above the surrounding terrain. Low velocity secondary impact craters investigated by Roberts (1964) and Hartmann (1967) also show raised rims. The same is true of the lunar craters under discussion in Figs. 8 and 9. In Fig. 10, the rim crest of the 30 m crater is the highest part of the panorama; and stereoscopic viewing of the Fauld crater itself, using the photographs reproduced in Figs. 2 and 3, also shows that its rim is topographically high. Clearly, a high rim is a necessary criterion for the explosive origin of the rim materials in any freshly formed crater. Thus, the similarities in the shapes, sizes and distribution of the rocks discussed above, taken together with the morphologic similarities of their parent craters on Earth and Moon, strongly support the theory that lunar craters of the type discussed here are of explosive origin.

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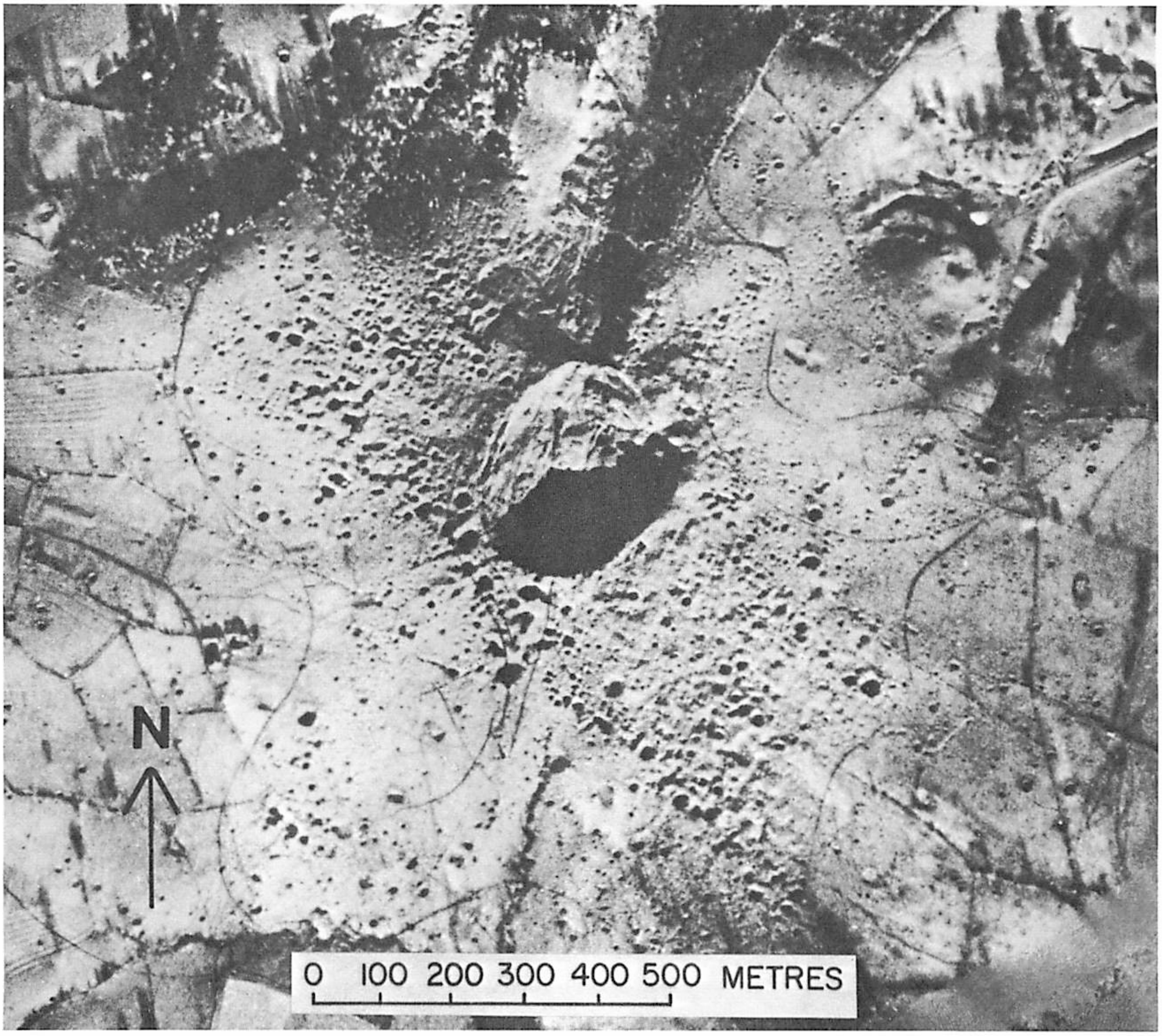

Fig. 1 Vertical air photograph of the Fauld crater and surroundings.

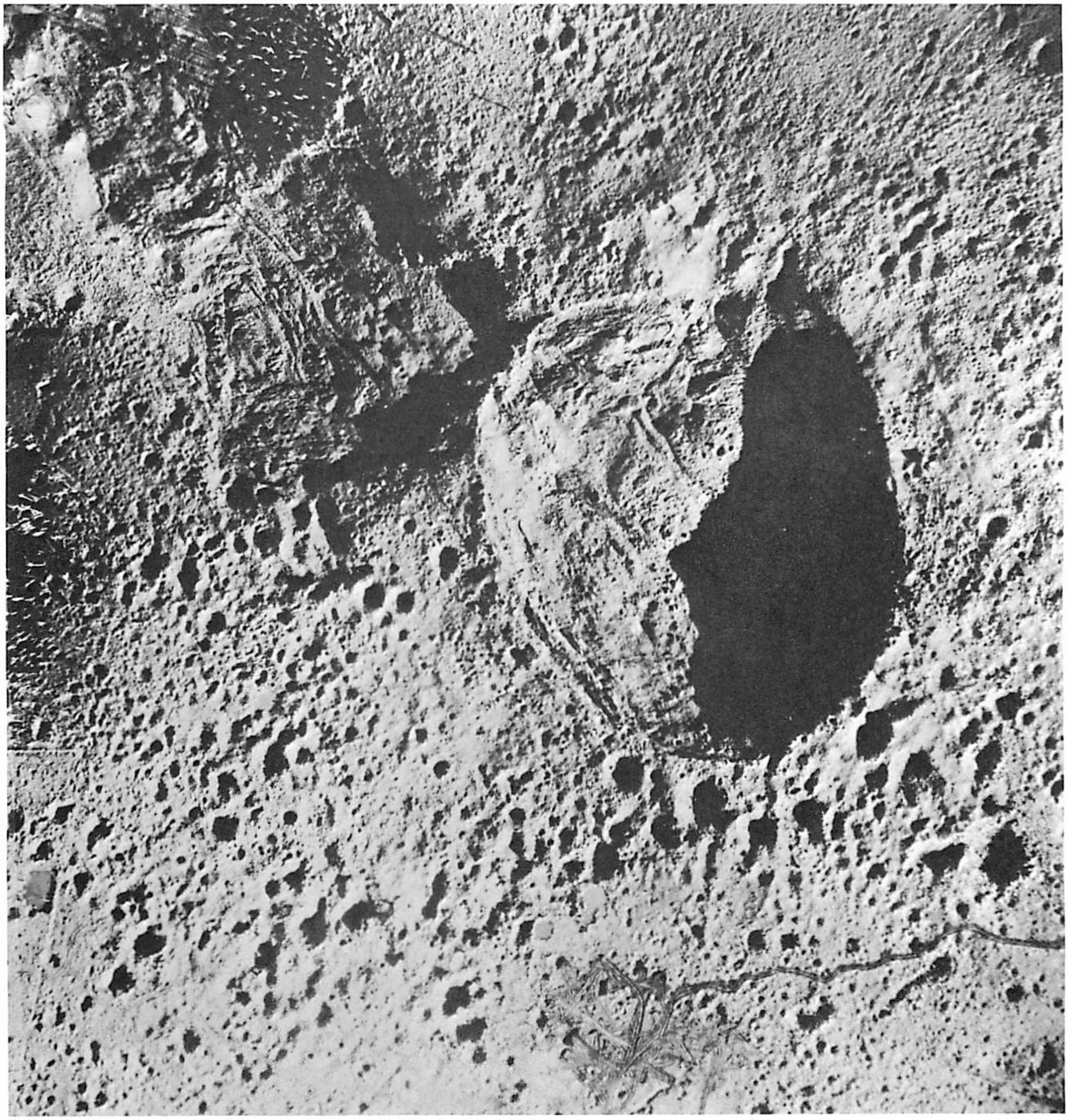

Fig. 2a Aerial view of Fauld crater, to be used with 2b (insert) for stereo view.

Fig. 2b (Comm. 114). Right half of stereo view of Fauld crater.

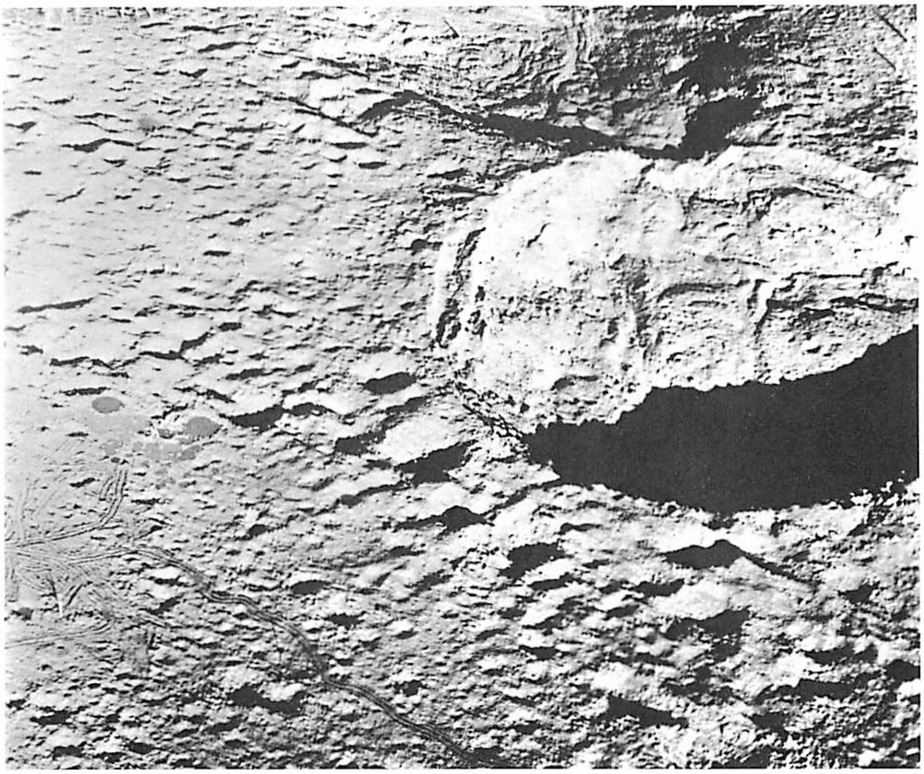

Fig. 3 Oblique aerial view of the Fauld crater showing bench along inner rim.

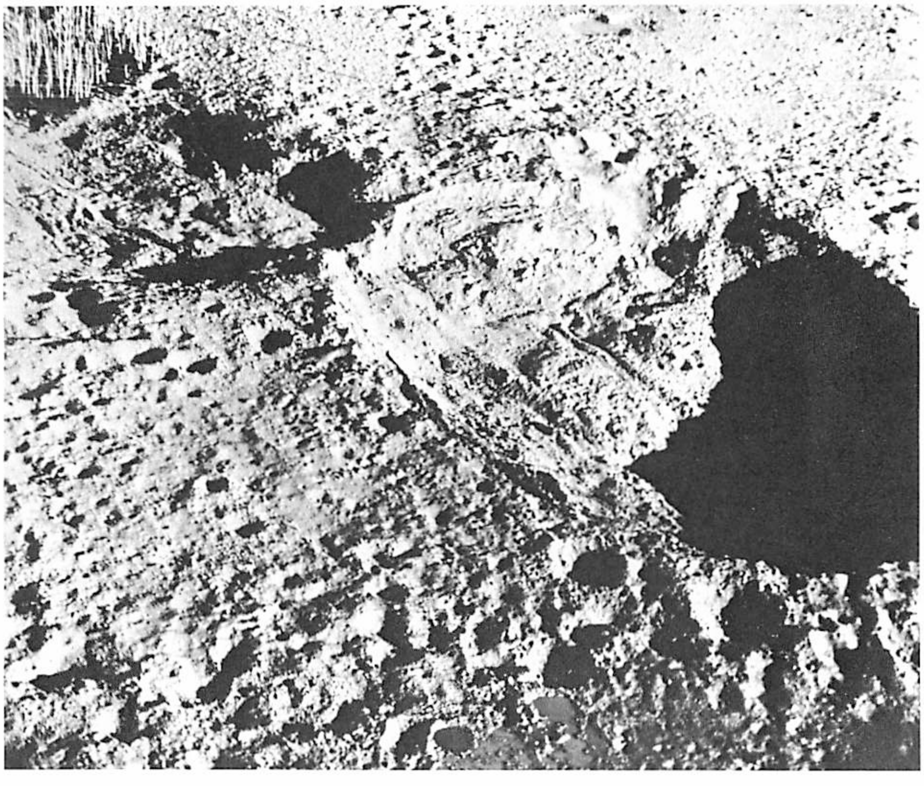

Fig. 4 Oblique aerial view of the Fauld crater showing bench along inner rim.

Fig. 5 Ground-based photograph taken in 1944 showing bench in Fauld crater.

Fig. 6 Ground-based photograph taken in 1967 showing slumping of materials forming inner rim of Fauld crater.

Fig. 7 Ground-based photograph taken in 1967 showing slumping of materials forming inner rim of Fauld crater.

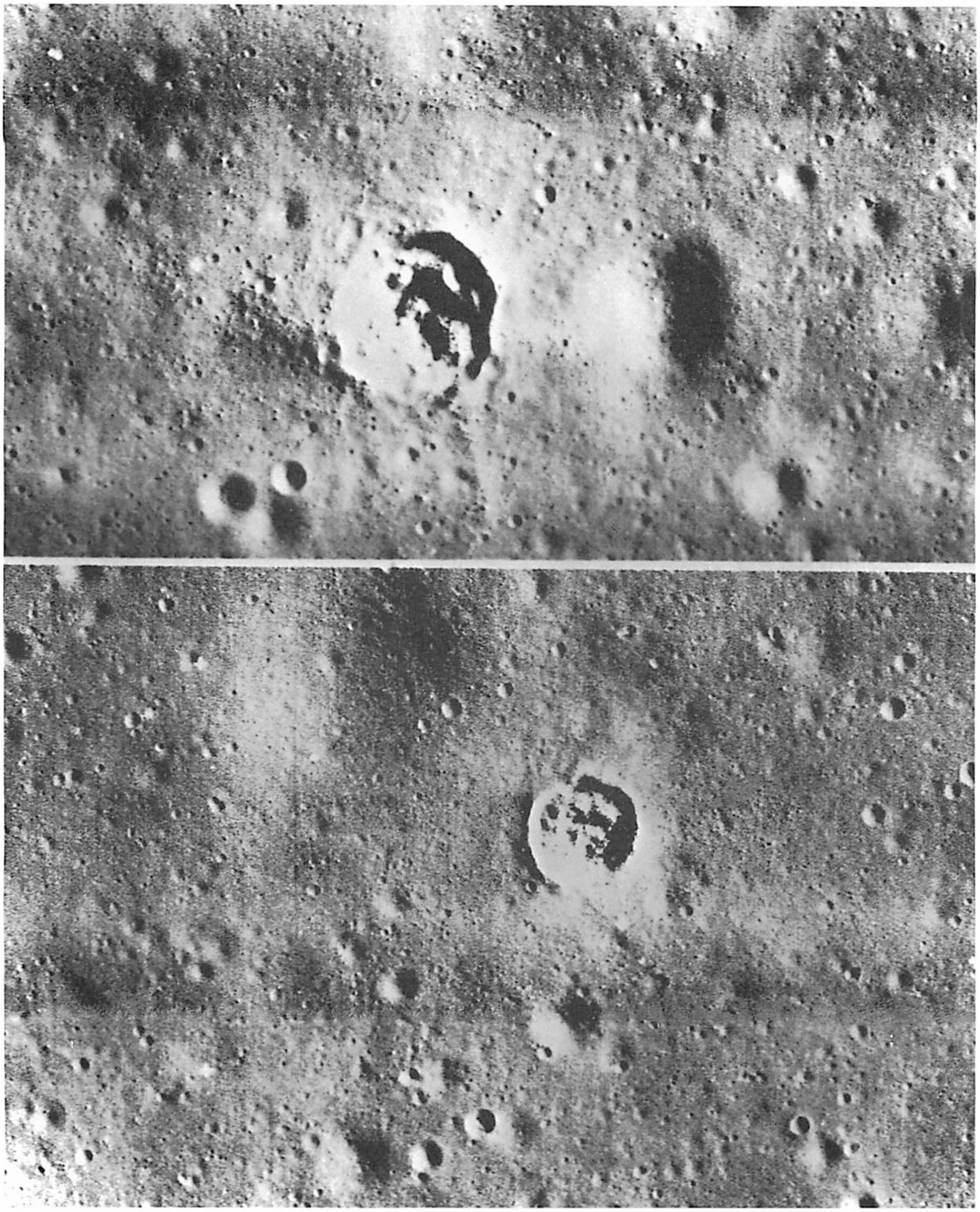

Fig. 8 Possible slumping in two lunar craters near Flamsteed in Oceanus Procellarum. The larger crater measures about 70 m in diameter and has rocks scattered around it. [*NASA Lunar Orbiter* III. H-194]

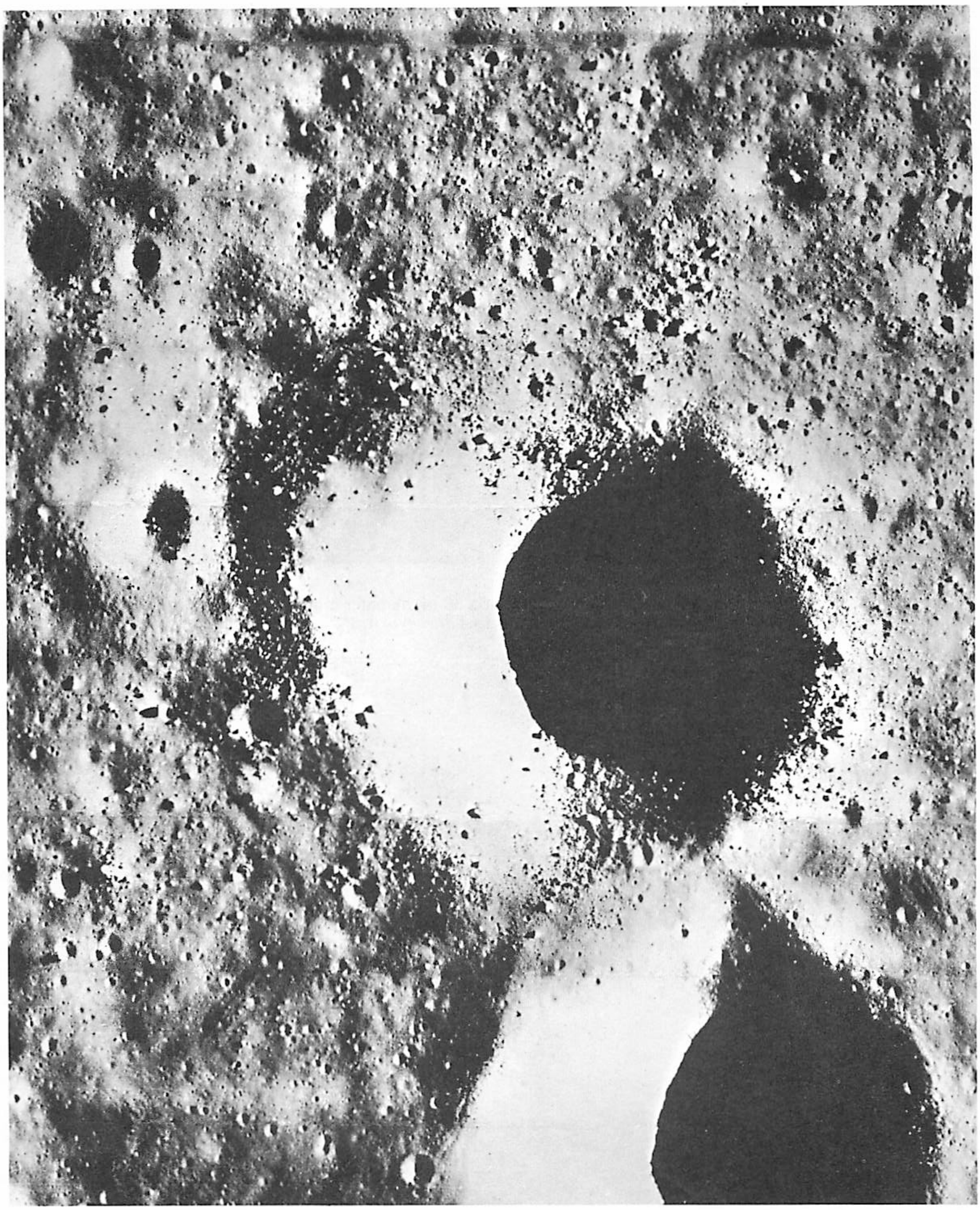

Fig. 9 Rocks around the rim of a lunar crater about 420 m in diameter, near Hortensius in Oceanus Procellarum [*NASA Lunar Orbiter* II H-161]

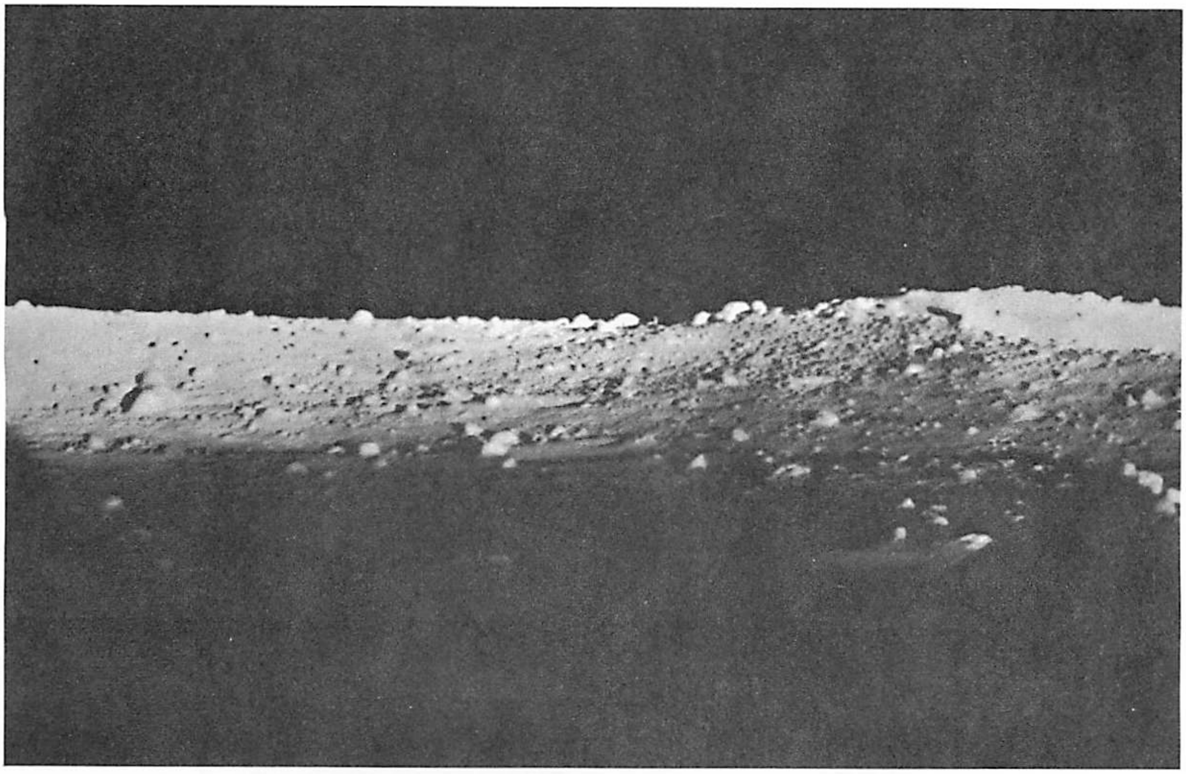

Fig. 10 This Surveyor I mosaic shows part of the rim of a 30 m diameter crater within the ring Flamsteed P. There are many rocks that appear to be related to the crater. [*NASA Surveyor* I, P.A. about 100°]

Fig. 11 Rocks on the rim of the Fauld crater.

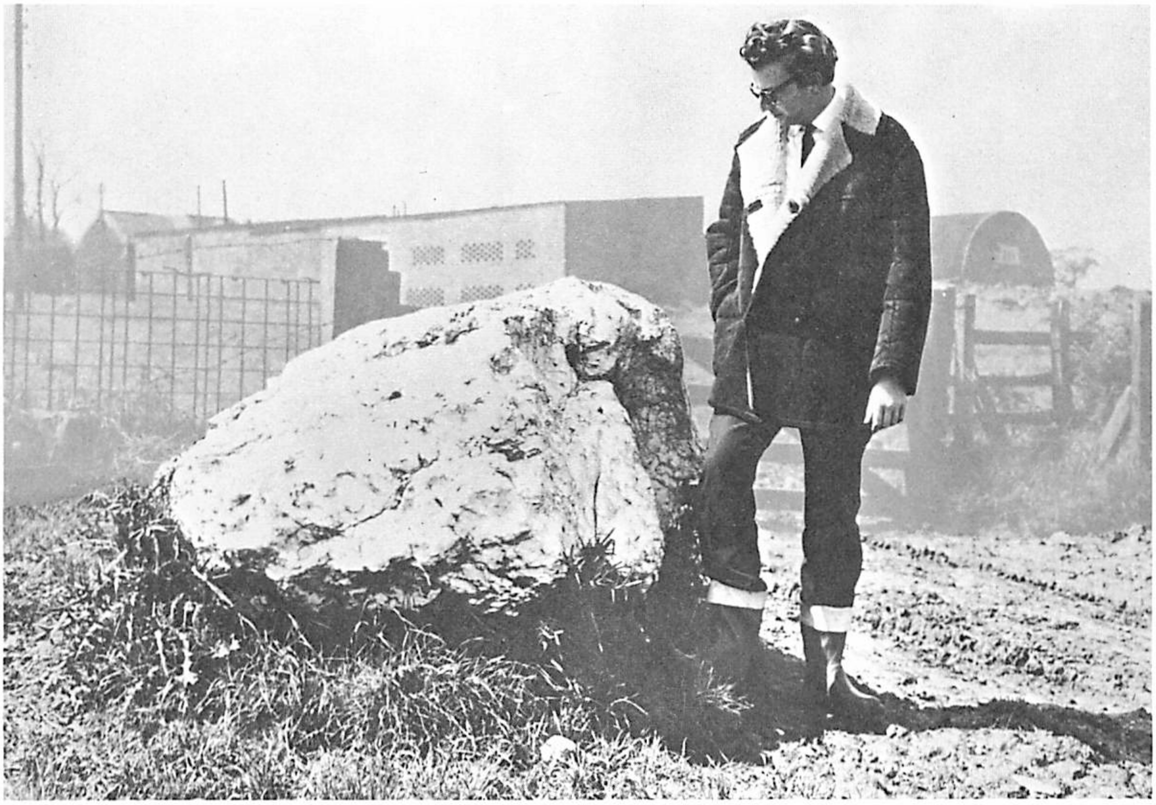

Fig. 12 Large block of ejected limestone about 400 m from the centre of the Fauld crater.

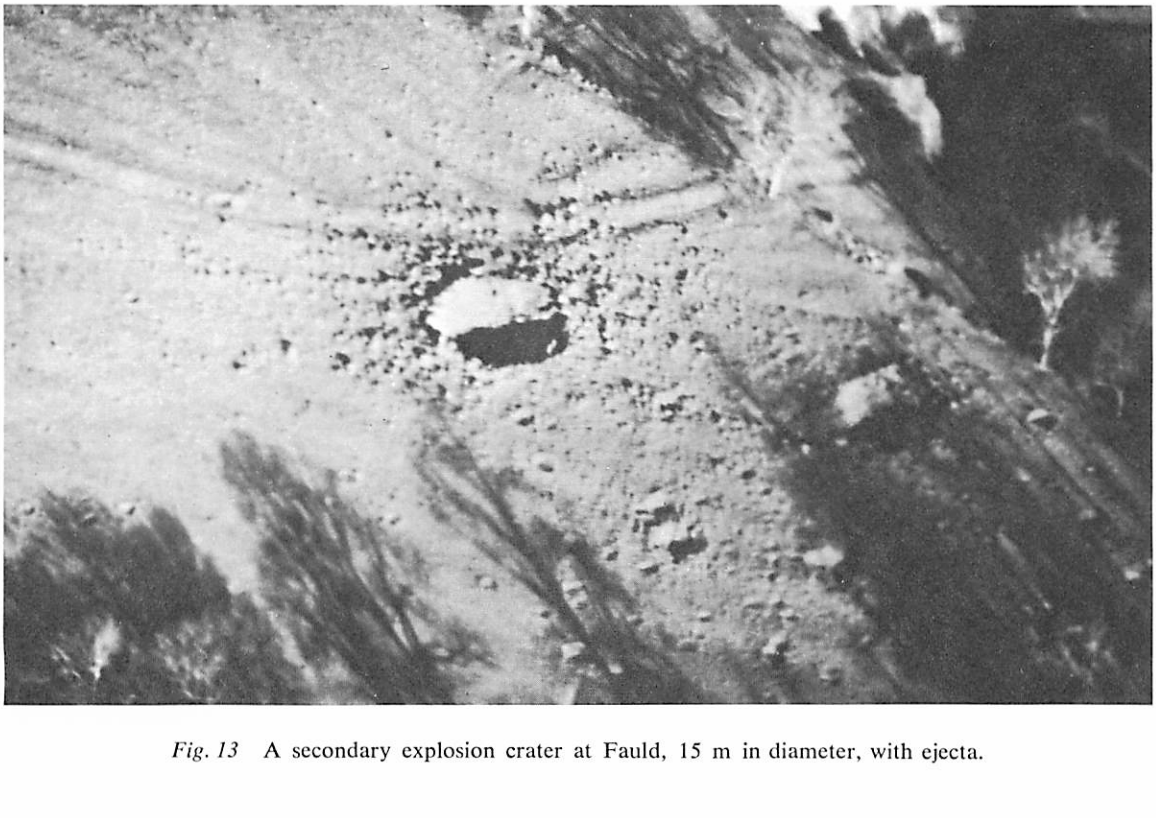

Fig. 13 A secondary explosion crater at Fauld, 15 m in diameter, with ejecta.