No. 59 FURTHER OBSERVATIONS ON THE RANGER VII RECORDS*

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As mentioned in No. 58, there is now considerable evidence to support the theory that the lunar maria were originally formed by processes involving the flow of material rather than by gradual dust transport or sudden deposition of shattered surface materials resulting from very large impacts. It is less easy to decide whether the maria are lava flows, ash flows, or combinations of the two, since one cannot readily predict the results of even terrestrial types of volcanic activity under the high vacuum and reduced gravity conditions existing at the lunar surface. However, one would expect a very porous, fragile structure for the surface layer in either case.

These original mare surfaces have presumably been subjected to at least the following modifying agents:

1. Mechanical stresses (tensions, compressions, shear stresses) due to tectonic motions in the mare beds, tidal effects, etc.
2. Bombardment by meteoritic bodies of all sizes
3. All solar radiations

The difficulty in trying to specify the present nature of the mare surfaces from a study of the *Ranger VII* records, made in conjunction with reliable Earth-based data, lies in predicting the effects of at least these three agents on the original surface layers, whose properties can only be surmised anyway.

It is generally agreed that large, ray-bearing craters such as Copernicus, Tycho, etc., were formed by the explosive energy release of massive bodies impacting the lunar surface at interplanetary velocities. It has not been established, however, whether the rays represent finely powdered lunar materials ejected from the explosion site, finely powdered debris of the impacting body, material displaced by the impact of chunks of lunar material hurled from the explosion site, the debris of these chunks, a combination of one or more of these effects, or some entirely different phenomenon (e.g., surface stains). Telescopic observation, study of good-quality Earth-based photographs, and now the *Ranger VII* records, show that those ends of ray elements lying closest to the parent crater apparently always contain a round or elongated crater, or cluster of craters. It is difficult to accept the first explanation as it stands, at least in the case of the more distant elements, because one cannot readily visualize tight clusters of ray material

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remaining intact over distances in excess of 1000 km, with each cluster containing crater-forming chunks which invariably reach the lunar surface before the ray material. An extreme case is the crater Messier A in Mare Fecunditatis (Fig. 1), which displays the well known "comet-tail" double ray, precisely radial to the more northerly of the two intense ray systems situated on the Moon's far side at 120°E longitude, 10°N latitude (derived from the *Lunik III* photographs). Another possible example is the crater Rosse in Mare Nectaris (Fig. 2), which is situated just beyond the apex of a major ray element of Tycho. The apex of this ray also appears to contain a small cluster of craters.

It seems, therefore, that at least in the case of the more distant ray elements, the ray material is associated in some way with those craters situated at the apices of the elements rather than with the parent crater, although the direction of the ray is clearly governed by the location of the parent crater. However, the difficulty now arises that the craters Messier A, Rosse, and a considerable percentage of the smaller craters located in the apices of the ray elements shown in the *Ranger VII* records are indistinguishable from what are usually considered to be meteorite impact craters. The only obvious difference is that some of the supposed meteorite craters display roughly circular nimbi or ray systems of their own. Since crater circularity suggests an explosive origin, why has the bright material all fallen to one side in the case of the ray craterlets? A possible explanation might be that any large disturbance of the lunar crust causes the release of trapped gases, vapors, etc. (e.g., from the permafrost layer postulated by T. Gold), and the expansion of these gases and vapors might cause a thin, temporary wind across the lunar surface. This wind might be expected to travel with velocities of an order of magnitude similar to those of the ejected chunks of material (from large ray craters such as Tycho). Fine material ejected by the collision of these chunks with the lunar surface would be transported downwind from the parent crater. The fact that many of the ray-element craterlets resemble explosion craters rather than collision scars might possibly be due to the sudden release of previously trapped gases or vapors on collision.

However, a major stumbling block to all of these explanations is the existence of such ray systems as those surrounding the small craters Stevinus A and Furnerius A (Fig. 2). The former crater, for example, has a diameter of about 7 km, and yet displays a straight ray over 1000 km in length. While the volume of the crater is sufficient to cover the entire ray area to a depth of almost 1 m, it is difficult to reconcile the perfect symmetry of the crater, suggesting a violent explosion, with the very marked asymmetry of the ray system. Furthermore, some of the secondary craters situated in the apices of the ray elements have diameters a considerable fraction of that of the parent crater. It seems very unlikely that the primary explosion could have produced blocks of a size sufficient to form the observed secondary craters, and that these blocks would largely be ejected in one preferred direction. In addition, this impact should have produced sufficient gas or vapor to fan ejecta from the secondary impacts for distances up to 1000 km is inconceivable.

Urey suggests elsewhere that large ray craters such as Tycho may have been caused by cometary collisions, the energy of the expanding dome of vaporized ices being largely responsible for the impetus given to the large masses which, he assumes, produced the secondary craters visible in several ray elements shown in the *Ranger* A frames. This explanation does not seem plausible in the case of the Stevinus A system, however.

An examination of high-quality full-Moon photographs shows that the majority of the small regular, conical craters, which are usually acknowledged as being due to high-velocity impacts, have no ray systems whatever. Yet, adjacent craters of indistinguishable shape, presumably formed in material of identical properties, may possess extensive ray systems. Similarly, the *Ranger VII* records show that the crater clusters seen in the apices of ray elements are frequently indistinguishable from other clusters which display no rays. This fact strongly suggests that the rays are not composed of lunar material. The existence of such asymmetric objects as the Stevinus A system shows that the rays are not composed of the fragmented impacting body either.

In order to try to account for these facts, the following suggestion is put forward. The small, conical type of craters which possess no trace of a nimbus or ray system have been formed by impacting meteorites, presumably similar to the stones and irons which still abound in the solar system. Craters possessing ray systems, however, were formed by the impact of comet nuclei.

Without elaborating details, it is suggested that the ray crater was formed by the impact of the main cometary nucleus, which consists of meteoritic types of bodies cemented together by frozen gases and vapors ("ices"). Detached fragments of the nucleus, and meteoritic material released by evaporation prior to impact, account

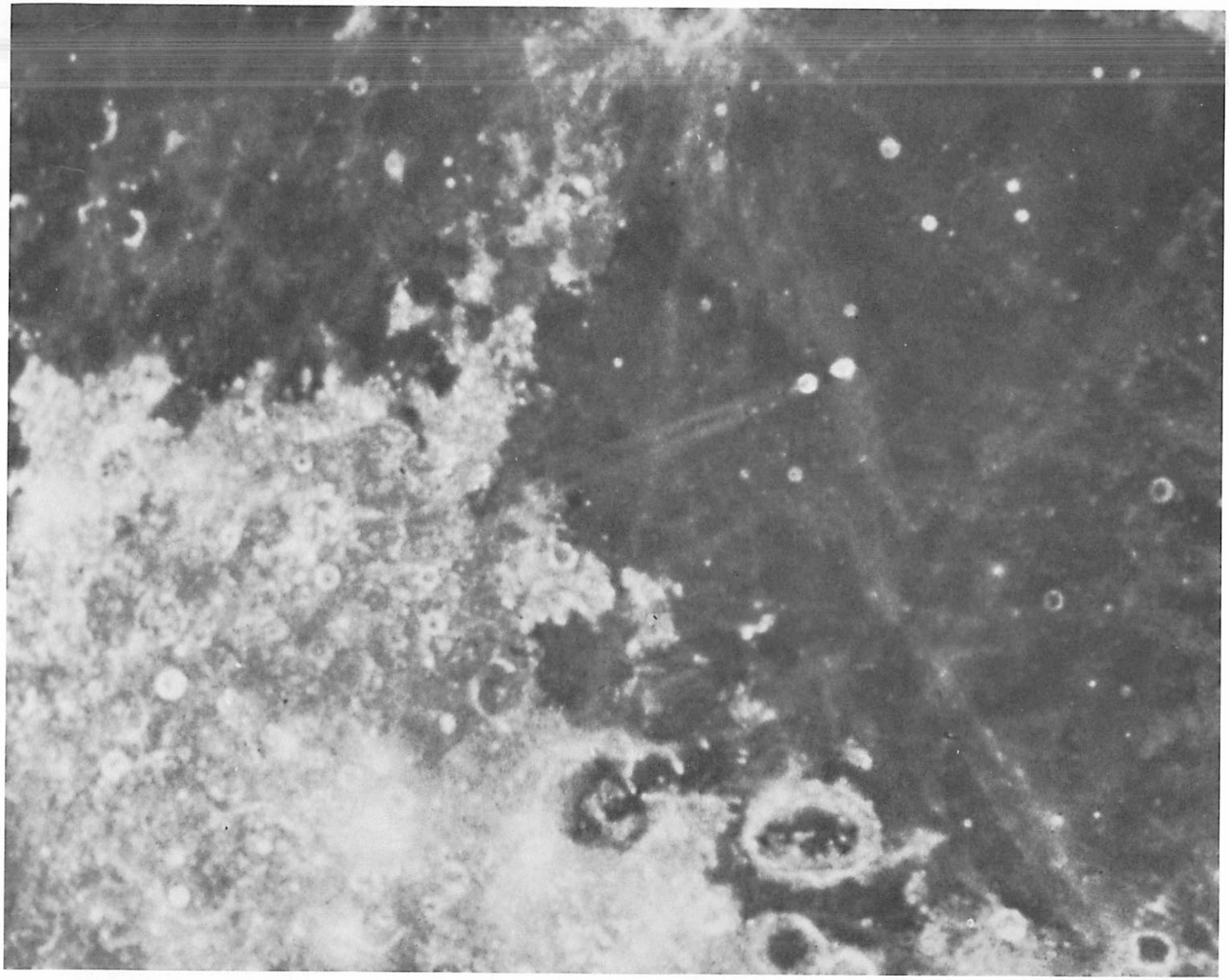

Fig. 1 Rectified view of Mare Fecunditatis at full Moon, showing the double ray associated with the craters Messier (right) and Messier A (left).

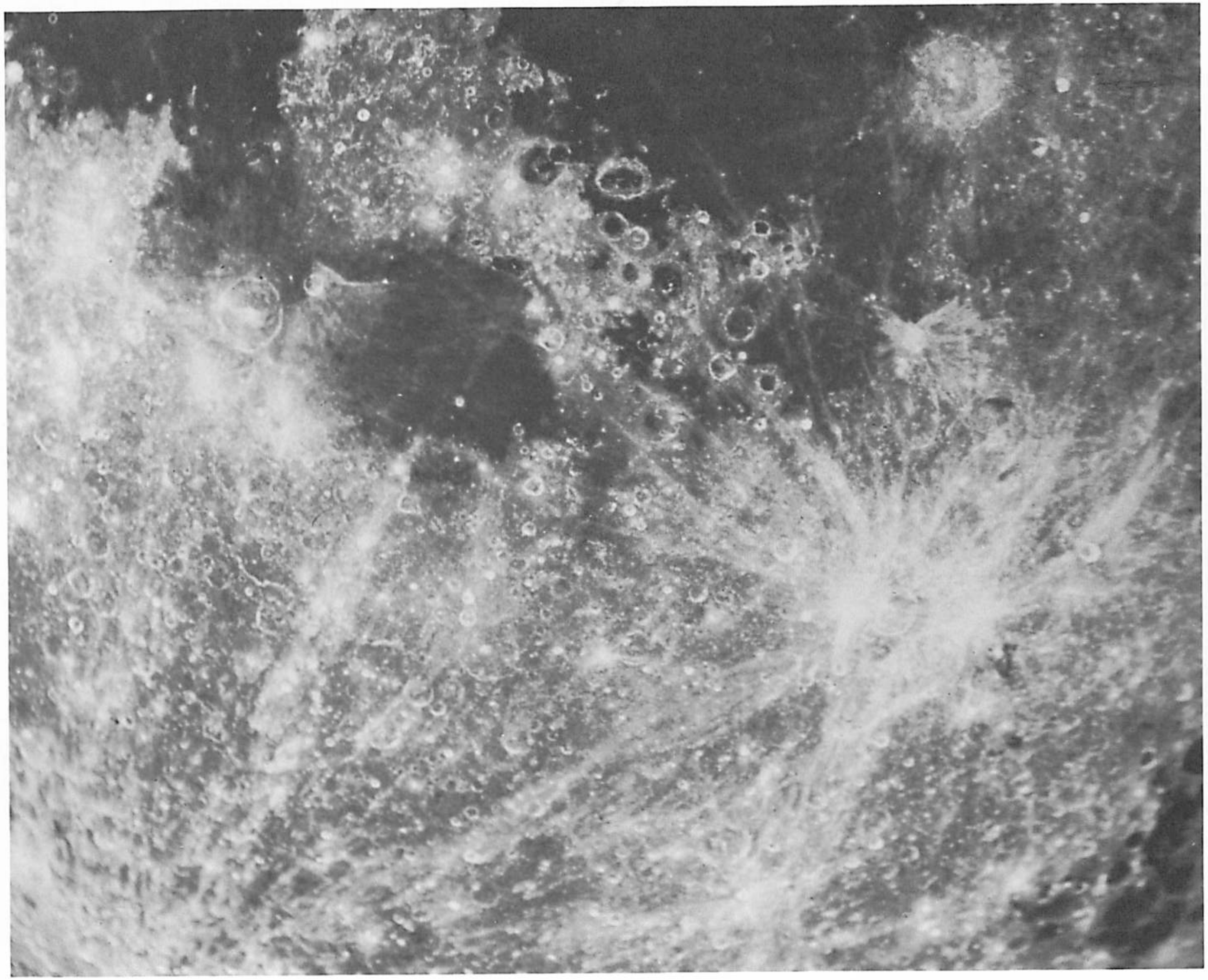

Fig. 2 Rectified view of the southern Mare Fecunditatis area showing the extensive ray systems associated with the small craters Furnerius A (right member of pair) and Stevinus A (left member of pair). The crater Rosse and its associated Tycho ray can be seen in Mare Nectaris (above and left of center).

for the rays and the "secondary" impact craters. The radial aspect of the rays is produced by the effect of the rapidly expanding dome of gases and vapors resulting from the almost instantaneous evaporation of the ices upon the still falling clots of meteoritic material. Under these conditions, the finer particles are deposited downwind from the heavier pieces, exactly as observed. If this assumption is correct, then asymmetric ray systems, like that of Proclus, are merely a reflection of the asymmetric distribution of detached meteoritic dust and other larger bodies around the original cometary nucleus. The long thin rays emanating from such craters as Stevinus A and Olbers A can be accounted for by the existence of strings of clots of meteoritic material in the vicinity of the cometary nuclei. This hypothesis differs from Urey's in that the former postulates that all lunar rays consist of cometary dust and debris, and that the "secondary" craters formed in clusters in and near ray elements are actually impacts.

Ranger VII impacted in the barely discernible boundary of a very minor ray which appears to be associated with Tycho. This ray is shown in all A-camera frames, while the higher-resolution P-camera frames feature areas in which the ray merges into imperceptibility. Other rays are recorded in many of the A frames. Wherever depressions do not interfere, the rays present an entirely unmottled appearance, no matter what the resolution. It is found that the ray areas tend to contain more shallow depressions than the non-rayed areas, although some of the latter display conspicuous clusters of such depressions. The depressions situated in the ray in which *Ranger VII* impacted exhibit a very marked NNE–SSW alignment; other depressions situated in non-rayed regions show precisely the same alignment, so that the apparent connection between rays and elongated depressions is presumably fortuitous.

The appearance of the elongated depression lying due south of the *Ranger VII* impact point is very suggestive of a collapse structure. The shaded area under the crest of the west wall is seen to consist of four or five straight segments, each of which lies parallel to one of the lineament systems of the entire mare and surroundings. Comparison between this depression and adjacent circular depressions fails to reveal any obvious structural differences. All of these observations suggest that the shallow, soft-edged depressions are not connected with lunar rays, that they are not impact structures, and that the rounding is not primarily due to erosion. It appears that the different apparent brightnesses of adjacent areas are due almost entirely to different angles and directions of slope, and that the tree-bark structure is rendered visible in the darker regions because of lower angles of illumination. This view has been further strengthened, since the completion of No. 58, by the production of a somewhat improved mosaic of the last few P frames, in which the tree-bark structure can be traced in many of the lighter areas as well as the darker ones (Fig. 3). This structure tends to follow contour lines, although the NNE–SSW direction appears to predominate in the more level areas.

Thus, the main segment of shade in the elongated depression lying south of the impact point, continued northward, passes through two P frames of high resolution, in which the tree-bark appearance is clearly visible. One may tentatively conclude, therefore, that the tree-bark appearance is the outward manifestation of a system of fractures, those in the more level regions having their origin in the same stresses which produced the overall lineament systems and those on the inner slopes of the soft-edged depressions being caused by tensions induced by the collapse or slumping of the floors.

The above observations lead to the following conclusions:

1. Smooth conical lunar craters are presumably formed by impacting solid meteoritic bodies.
2. The larger ray systems appear to be more readily explainable on the basis of impacts with cometary nuclei. The ray crater is assumed to be formed by the impact of the main nucleus. The rays are assumed to be thin deposits of cometary dust, fanned radially by the expanding gas and vapor dome produced by the vaporized ices. The craters situated in or near the apices of the ray elements are assumed to have been formed by the impacts of meteoritic bodies or clots of meteoritic material loosely or partially cemented together by ices, which had become detached from the main nucleus prior to impact through evaporation of ices by solar radiation.
3. The ray material is evenly distributed, and has not been deposited in discrete clumps. The general dimness of the Mare Cognitum rays, as compared with bright rays, suggests that nowhere do these rays completely blanket the mare surface material.
4. The shallow, round or elongated, soft-edged depressions seen in some of the ray elements are believed to have no connection with the rays. They are tentatively assumed to be collapse features.

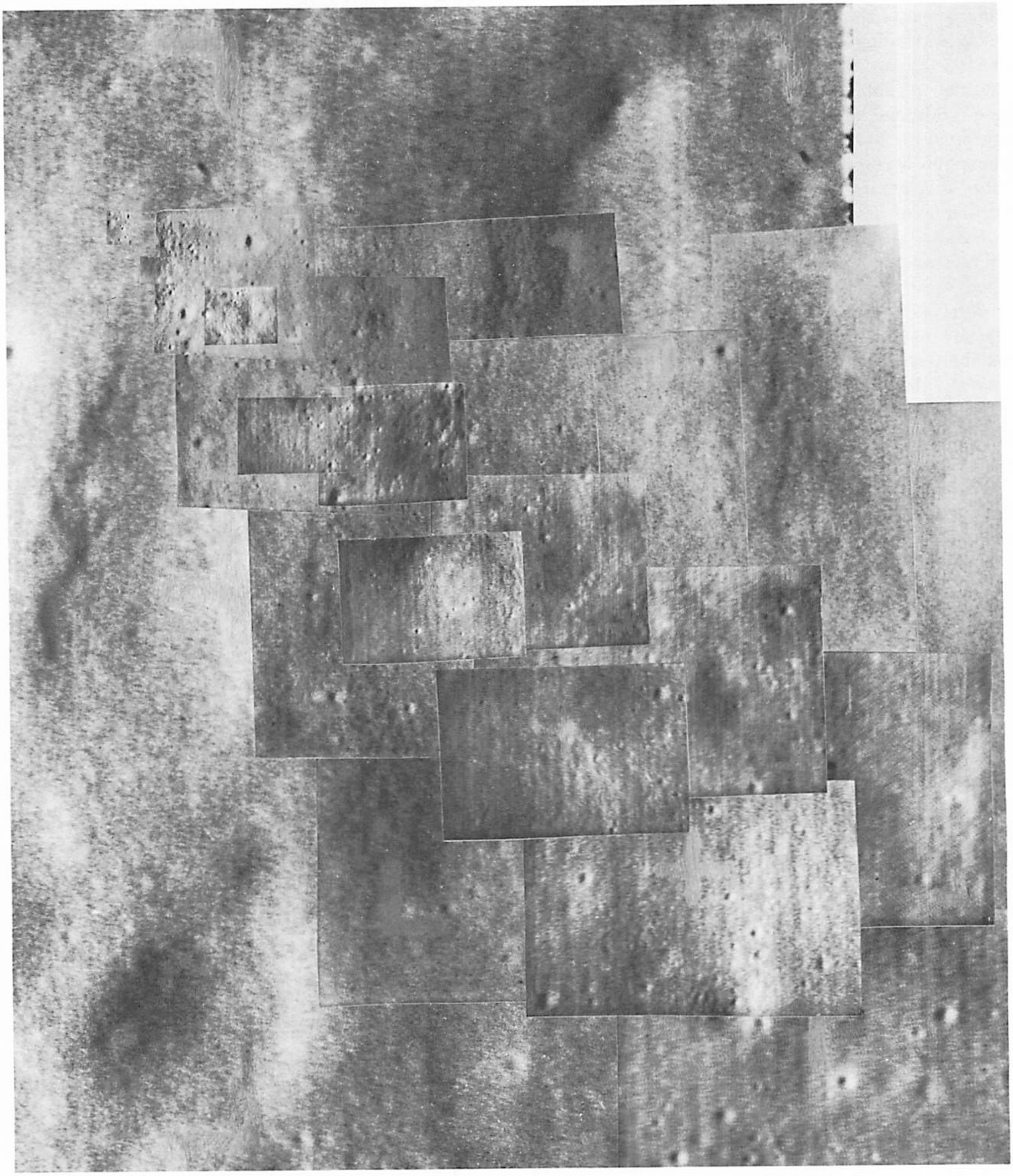

Fig. 3 Mosaic of the last few P frames on a portion of the last A frame. (Although densities are not well matched, the "tree-bark" structure is readily visible.)

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