Observations of Mare Serenitatis from lunar orbit and their interpretation

FAROUK EL-BAZ
National Air and Space Museum
Smithsonian Institution, Washington, D.C. 20560

and

R. E. EVANS
Astronaut Office
Johnson Space Center, Houston, Texas 77058

Abstract: Visual observations of color differences of Serenitatis mare materials from orbit complement photography and other remotely sensed data. The light tan gray inner fill of the Serenitatis basin is younger than the dark blue gray annulus; the latter continues into and appears to be contemporaneous with the fill of Mare Tranquillitatis. Mare ridges occur in both the inner basin fill and the dark annulus of Serenitatis. Ridges are interpreted as the result of structural deformation and up-doming after the solidification of the basaltic lavas.

On the southeastern rim of the Serenitatis basin is the darkest blue gray unit within which Apollo 17 landed. Highland massifs surrounding this unit have unstable slopes which are believed to be the result of localized tectonic activity. On the southwest rim of the basin are the dark tan to brown gray mantling materials of the Sulpicius Gallus Formation. Farther west on the rim are dark blue gray patches which resemble the mare material of the Serenitatis dark annulus.

(NASA-TM-X-70209) OBSERVATIONS OF MARE SERENITATIS FROM LUNAR ORBIT AND THEIR INTERPRETATION (NASA) 18 p HC $4.00 CSCL 03B
N74-29245
Unclas
G3/30 15982

INTRODUCTION

The objective of visual observation from lunar orbit to complement photography and other remotely sensed data was successfully fulfilled on Apollo 17. Because the Apollo 17 ground coverage duplicated about 80% of that of Apollo 15, much was known about the overflown areas. For this reason emphasis was placed on the study of color tones of lunar surface units and on the details of small scale features. A selection of the comments made while in lunar orbit will appear in the Apollo 17 Preliminary Science Report (Evans and El-Baz, 1973). This paper summarizes the orbital observations relating to Mare Serenitatis. Photogeologic interpretations are included to confirm these observations and to point out their geological significance.

COLOR BOUNDARIES

The mare fill of the Serenitatis basin has long been known to display units with different albedo characteristics. It includes some of the darkest (low albedo) units on the Moon (Pohn and Wildey, 1970; El-Baz, 1972a). There is correlation between the albedo units and color units detected by special photographic and photoelectric methods (Whitaker, 1972; Strom, 1972).

An attempt was made on Apollo 17 to discern the color boundaries and to elucidate their relationships to other notable color differences in adjacent maria. The importance of this stems from groundtruth data which indicates that color differences reflect compositional variations;

e.g., the darker and bluer the mare, the more titanium in the basalt. The Apollo 11 and 17 sites are both located in dark mare units; the mare basalts of both sites, as established by numerous investigators, are relatively rich in titanium (Strom, 1972).

As shown in Figure 1, Mare Serenitatis displays two major albedo units. The inner fill of the basin is characterized by a higher albedo than that of the darker annulus. The latter was previously believed to be the younger of the two units (Carr, 1966; Wilhelms and McCauley, 1971; El-Baz, 1972a; and others). As will be shown below, Apollo 17 provided contrary evidence, through visual observations and orbital photographs, that the lighter colored inner fill is younger than the dark annulus.

In addition to the dark annulus within the basin there are darker areas on the southeastern and southwestern parts of the basin's rim. Refering to these color differences, the CMP made the following comment during the Apollo 17 mission: "To me the Moon has a lot more color than I had been led to believe. (Prior to the mission) I had the impression that everything was the same color. That is far from being true."

In the following discussion the regions of eastern, southern and western Serenitatis will be treated separately.

A. Eastern Serenitatis

The dark material on the southeastern rim of the Serenitatis basin (Fig. 2) is dark gray with a bluish tint. During the mission, the CMP stated that it is similar in color to the dark floor fill of Maraldi Crater to the east. At both localities, he also noted the presence of bluish gray blocks around larger craters; e.g., the 300-600 m craters clustered

in the Apollo 17 landing site area (Fig. 3).

Prior to Apollo 17, photogeologic investigations suggested that the darker unit is relatively young (e.g., El-Baz, 1972a). This was based primarily on the smooth appearance of the surface. In addition, the premise that the bluer maria are younger (Whitaker, 1972), the relatively low number of craters within the dark unit (Greeley and Gault, 1973), and the probability of the presence of a source of a pyroclastic mantle in the form of volcanic vents or cinder cones in the area (El-Baz and Worden, 1972), also suggested that the darker unit is relatively young. Earth-based radar and IR studies (Thompson et. al, 1973) also supported the interpretation of an unusually smooth surface, which suggests a low crater density and therefore a relatively young surface.

Age dating results indicate that the basalts of the Taurus/Littrow landing site are similar in age to the Apollo 11 basalts, about 3.7 b. y. old (Tera et. al, 1973). The dark color is probably due to the high titanium content of the basalts (Strom, 1972) and/or a moderate amount of dark glass beads and fragments in the soil samples. There is also photographic evidence that the mare material on the southeast rim of Mare Serenitatis is embayed by, and therefore older than, the dark annulus materials (Fig. 2).

B. Southern Serenitatis

Perhaps the sharpest demarcation between the two major units of Serenitatis is in the southern part of the basin north of the craters Plinius (Fig. 4) and Menelaus. Materials of the outer annulus are dark blue gray in color, with a slight tannish tone. The mare in the inner part of the basin is light tan gray.

As shown in Figure 4, the mare of the dark annulus is more textured (with small scale undulations and numerous arcuate rilles and lineaments) and has more craters per unit area than the mare of the inner basin. The superposition relationships are also clear: Rilles and other depressions in the older annulus are encroached and flooded by the lighter and younger unit. The broad mare ridge which is a relatively young feature is also confined to the light-colored unit.

C. Western Serenitatis

The dark blue gray mare material of the Serenitatis annulus is exposed in the western part near Sulpicius Gallus Crater, and the exposure continues northward in a broad zone beyond the point of merger of Mare Serenitatis and Mare Imbrium. Another dark unit is exposed in the area of the Sulpicius Gallus Rilles on the western rim of the Serenitatis basin. This unit has a dark brownish tint. It appears to fill valleys and thinly mantle small hills between the Haemus Mountains, whose tops are not mantled. The color and texture of this unit differ from those of other terra mantling materials farther to the west, which form smooth and flat patches of blue-gray materials (Fig. 5).

The Sulpicius Gallus Rilles themselves are located in a dark brownish gray unit that appears to mantle the rim materials of the Serenitatis basin. This unit has been mapped as the Sulpicius Gallus Formation (Carr, 1966). It is in this area that several craters, probably of impact origin, and irregular elongate depressions of unknown origin, have a rust-colored or orange tint. Since the same tint was observed from orbit on the north flank of Shorty Crater (Evans and El-Baz, 1973), it is reasonable

assume that the orange colors at both localities are caused by the presence of orange-tinted glass beads which may be either volcanic or impact in origin.

MARE RIDGES

One major system of wrinkle ridges, and several subsidiary ridges occur in Mare Serenitatis. The major circular system occurs within the lighter colored inner mare material of Serenitatis. The subsidiary ridges that are either subparallel to the major ridge system or radial to it, occur in both units of Mare Serenitatis.

One prominent subsidiary ridge is in the eastern part of Mare Serenitatis. A part of this ridge unusually laps up against the southwestern corner of the flooded crater Le Monier (Fig. 6). It continues to the south as a broad ridge, with sharp discontinuous escarpments near its borders. This characteristic is also common along the major ridge system (Fig. 6).

Figure 4 illustrates an example of a radial subsidiary ridge. As is common, there are no crosscut relationships with the main circular ridge, and both appear to have formed contemporaneously. In this particular example, the ridge abuts against the older mare material that forms the dark annulus near the rim of Serenitatis. There are however, cases where subsidiary ridges extend through the darker annulus, such as in the southeastern corner of Mare Serenitatis (El-Baz, 1972a).

In most cases, there is clear evidence of correlation between the Serenitatis mare ridges and fault systems in and around the basin (El-Baz, 1972a). It was previously shown (El-Baz, 1972b) that relatively young

mare flows in southwestern Mare Imbrium are pushed upward by ridges of substantial elevation, which suggests that the ridges are younger than the flows. This and superposition of ridges on mare materials of Serenitatis indicate that the ridges are formed after the emplacement and solidification of the lava fill. The ridges are best explained by thrusting up of the solid materials, with the exception of a few small extrusions and flow like features that were probably fluid in the eastern part of the Serenitatis ridge system (Strom, 1972).

HIGHLAND UNITS

Highland or terra units that surround the landing site (both massif units and sculptured hills) constitute the best exposures of Serenitatis rim materials. They were studied from orbit and compared to materials surrounding Crisium and Imbrium basins.

Massif units surrounding the Taurus-Littrow valley have an unusually high albedo. A concentration of blocks occurs on the tops of the massifs that is matched only on the tops of central peaks of relatively fresh craters such as Tsiolkovsky. Evidence of downslope movement of material including numerous tracks of downward moving blocks (Fig. 7) suggests that the massifs have unstable slopes. The light mantle in the landing site area (Fig. 3) is believed to be a landslide that originated from South Massif (El-Baz, 1972a).

Massif units of comparable size surrounding Mare Crisium and Mare Imbrium do not show similar features, although both Crisium and Imbrium basins are believed to be younger than the Serenitatis basin (Wilhelms and McCauley, 1971). Block exposures and downslope movement of material

on the Serenitatis massifs may have been triggered by relatively recent tectonic activity in the area; one possibility is the tectonic movement that formed the Scarp (Fig. 3).

The Sculptured Hills have a lower albedo than that of the massifs ("intermediate between that of the massifs and the dark mantle"), and are light gray in color. These hills which dominate the terrain north and east of the landing site area are believed to be of different origin from hilly units surrounding Mare Crisium, although both give the so-called corn-on-the-cob appearance at high Sun elevation angles. The sculpturing is believed to have been enhanced by accumulation of dark materials in grooves between the highland hills.

CONCLUSIONS

The low albedo material which forms the dark annulus of Mare Serenitatis has the same color and albedo as the fill of most of Mare Tranquillitatis. This is supported by similarities in chemistry and in crystallization age of the Apollo 17 and Apollo 11 mare basalts. Mare material of the dark annulus appears to be flooded by and therefore older than the lighter mare fill in the inner part of the Serenitatis basin.

To summarize the colors of the mare units of Serenitatis as observed from orbit: The inner fill of the basin is light tan gray; the outer annulus is dark blue gray; the Taurus-Littrow valley where the Apollo 17 LM landed is a darker blue gray; the Sulpicius Gallus Formation is dark tan to brown gray and the mare-like patches between the Haemus and Apennine Mountains are, like the annulus materials, dark blue ray.

These color characteristics are important in extrapolating ground-truth data to larger areas of the Moon, as well as in the interpretation of results of both Earth-based and orbital geochemical and geophysical remote sensing.

A circular major ridge system is located in the light inner mare fill of Serenitatis. Subsidiary ridges, both subparallel and radial to the major system occur in both the light inner mare and in the dark annulus, but none appear to be directly related to the lava extrusion. The ridges are probably due to structural deformation after the solidification of the mare lavas.

The brightness of the Serenitatis massifs, the numerous blocks that crown them, the tracks of downward moving blocks, as well as the landslide that is believed to have formed the light mantle in the Apollo 17 landing site are believed to be indications of relatively late tectonic movement. One possibility is the displacements that resulted in the formation of the Scarp, which is probably older than the slide.

REFERENCES

Carr M. H. (1966) Geologic map of the Mare Serenitatis region of the moon. U. Geol. Surv. Misc. Geol. Inv. Map I-489.

El-Baz F. (1972a) The cinder field of the Taurus Mountains. In Apollo 15 Preliminary Science Report NASA SP-289, pp. 25-67 to 25-71.

El-Baz F. (1972b) New geological findings in Apollo 15 lunar orbital photography. Proc. 3rd Lunar Sci. Conf. Vol. 1, pp. 39-61.

El-Baz F. and Worden A. M. (1972) Visual observations from lunar orbit. In Apollo 15 Preliminary Science Report NASA SP-289, pp. 25-1 to 25-27.

Evans R. E. and El-Baz F. (1973) Geological observations from lunar orbit. In Apollo 15 Preliminary Science Report NASA SP-330 (in press).

Pohn H. A. and Wildey R. L. (1970) Photoelectric-photographic study of the normal albedo of the moon. U.S. Geol. Surv. Prof. Paper 599-E.

Greeley R. and Gault D. E. (1973) Crater frequency age determinations for the proposed Apollo 17 site at Taurus-Littrow. Earth & Planet. Sci. Let., Vol. 18, pp. 102-108.

Strom R. G. (1972) Lunar mare ridges, rings and volcanic ring complexes. In The Moon: International Astronomical Union, Symp. No. 47 Runcorn S. K. and Urey H. C. editors, pp. 187-215.

Tera F. Papanastassiou D. A. and Wasserburg G. J. (1973) A lunar cataclysm at ∿ 3.95 Æ and the structure of the Lunar Crust. In Lunar Science Chamberlain J. W. and Watkins C. editors Lunar Science Institute, pp. 723-725.

Thompson T. W. Shorthill R. W. Whitaker E. A. and Zisk S. H. (1973) Complex origin of Mare Serenitatis floor: Synthesis of remote observations. In Lunar Science IV. Chamberlain J. W. and Watkins C. editors. Lunar Science Institute, pp. 726-727.

Whitaker E. A. (1972) Lunar color boundaries and their relationship to topographic features: a preliminary survey. The Moon Vol. 4, pp. 348-355.

Wilhelms D, E. and McCauley J. F. (1971) Geologic map of the nearside of the moon. U.S. Geol. Surv. Misc. Geol. Inv. Map I-703.

CAPTIONS OF FIGURES

Figure 1. Oblique view looking westward across Mare Tranquillitatis (left) and Mare Serenitatis (right) showing the similarity in apparent albedo and color of Tranquillitatis and the dark annulus of Serenitatis. The dark patch on the southeastern rim of Serenitatis is shown in more detail in Figure 2. Apollo 17 Hasselblad 152-23328.

Figure 2. The dark area (center to lower edge) between highland massifs in the southeastern rim of Mare Serenitatis. At center of upper edge of photograph, the mare fill of the Serenitatis basin (the dark annulus material) appears to truncate, and therefore is younger than, the dark unit on the Serenitatis basin rim material (the darkest unit); see also Lunar Orbiter V, frame 66-M.

Figure 3. The Apollo 17 Taurus-Littrow landing site. The two massif units are separated by 8 km wide dark deposit on which a light mantle is superposed. Blue gray colored blocks were observed in the cluster of craters near the right edge. The Scarp which bisects the dark deposit continues across the lower slopes of North Massif in a northwesterly trend. Apollo 17 Hasselblad frame 150-23006.

Figure 4. Albedo/color boundary in southern Mare Serenitatis north of the crater Plinius whose rim appears on the lower edge of the photograph. Portion of the circular mare ridge system appears on the upper edge of the photograph; a subsidiary ridge that is radial to it abuts against the older and darker mare unit in the middle of the photograph. Apollo 17 Hasselblad frame 150-23069.

Figure 5. Oblique view looking westward of the western rim deposits of the Serenitatis basin. The dark blue gray material of the Serenitatis annulus is in the lower right corner. The Sulpicius Gallus Rilles (right edge) and the unit in the near field are tan to brown gray in color. This is contrasted to patches in the background of dark blue gray mare-like materials. Apollo 17 Hasselblad frame 153-23571.

Figure 6. Ridge systems of eastern Mare Serenitatis: top, portion of the subsidiary ridge system in the dark annulus near the southwestern rim of Le Menier Crater (Apollo 17 Hasselblad frame 153-23496); bottom, portion of the major circular ridge system showing the sharp escarpments on both sides of the broad ridge (Apollo 17 Hasselblad frame 150-23021).

Figure 7. View from the Taurus-Littrow valley of North Massif showing boulders (some are circled)that moved downslope leaving conspicuous tracks. Apollo 17 Hasselblad frame 147-22549.

Reproduced from best available copy.

Figure 1

El-Baz : Observations of Mare Serenitatis

Figure 2

El-Baz : Observations of Mare Serenitatis

Reproduced from best available copy.

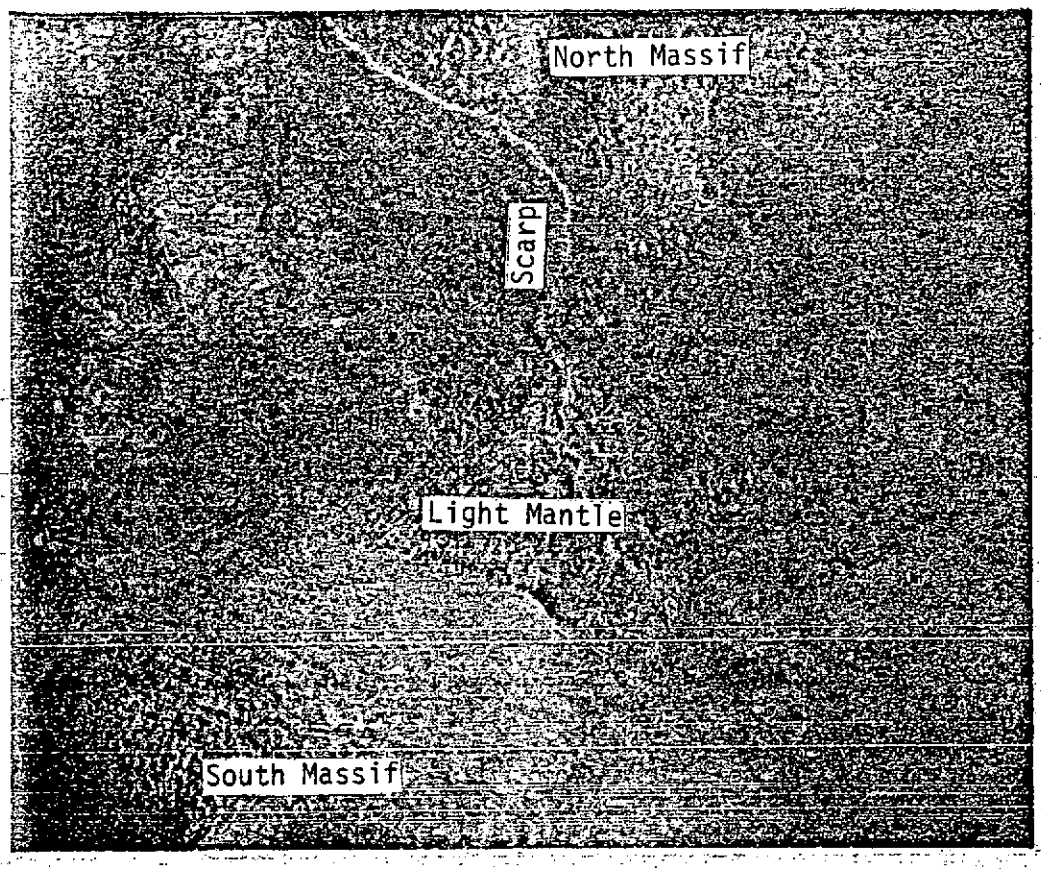

Figure 3

El-Baz: Observations of Mare Serenitatis

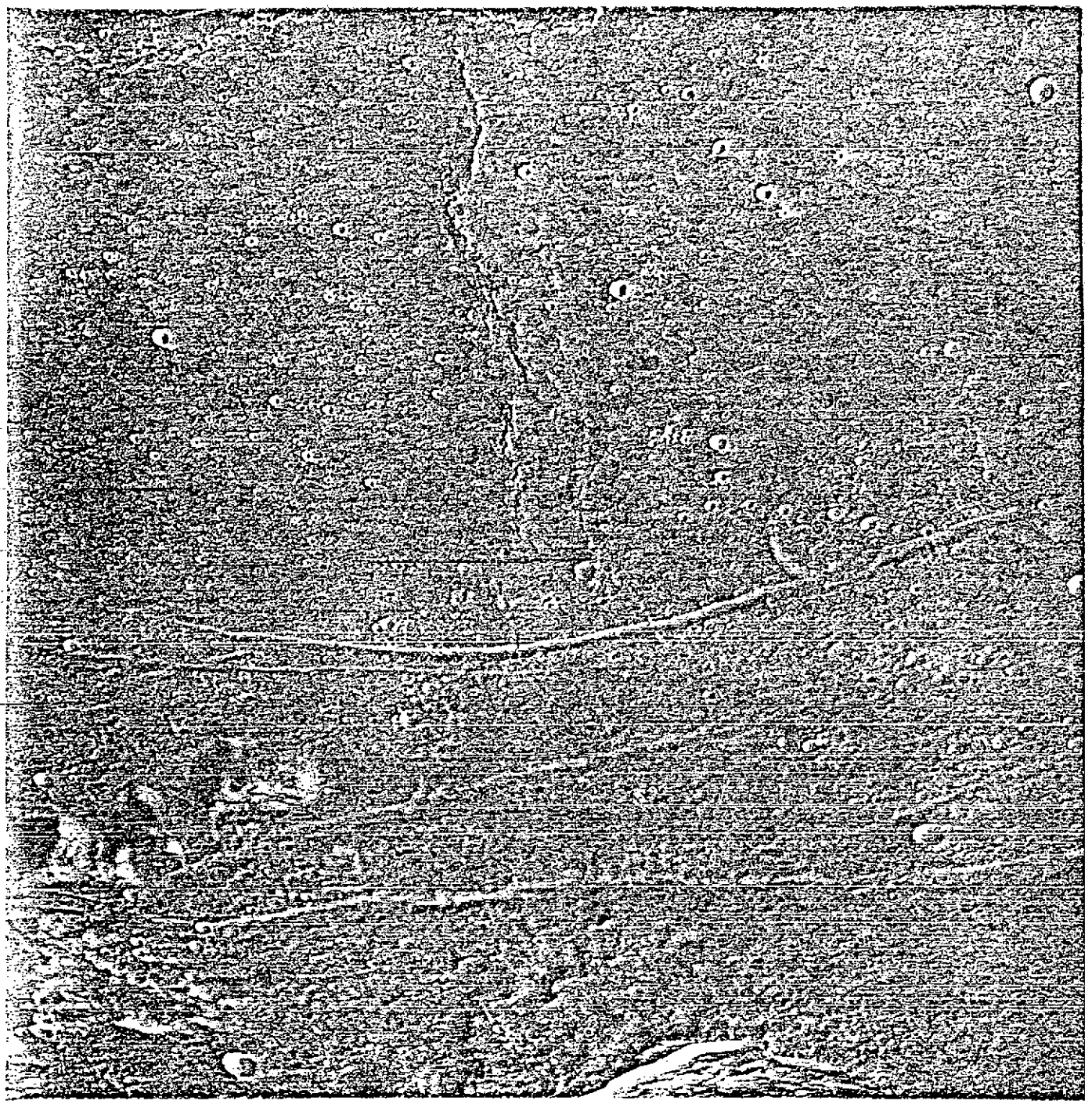

Figure 4

El-Baz : Observations of Mare Serenitatis

Reproduced from best available copy.

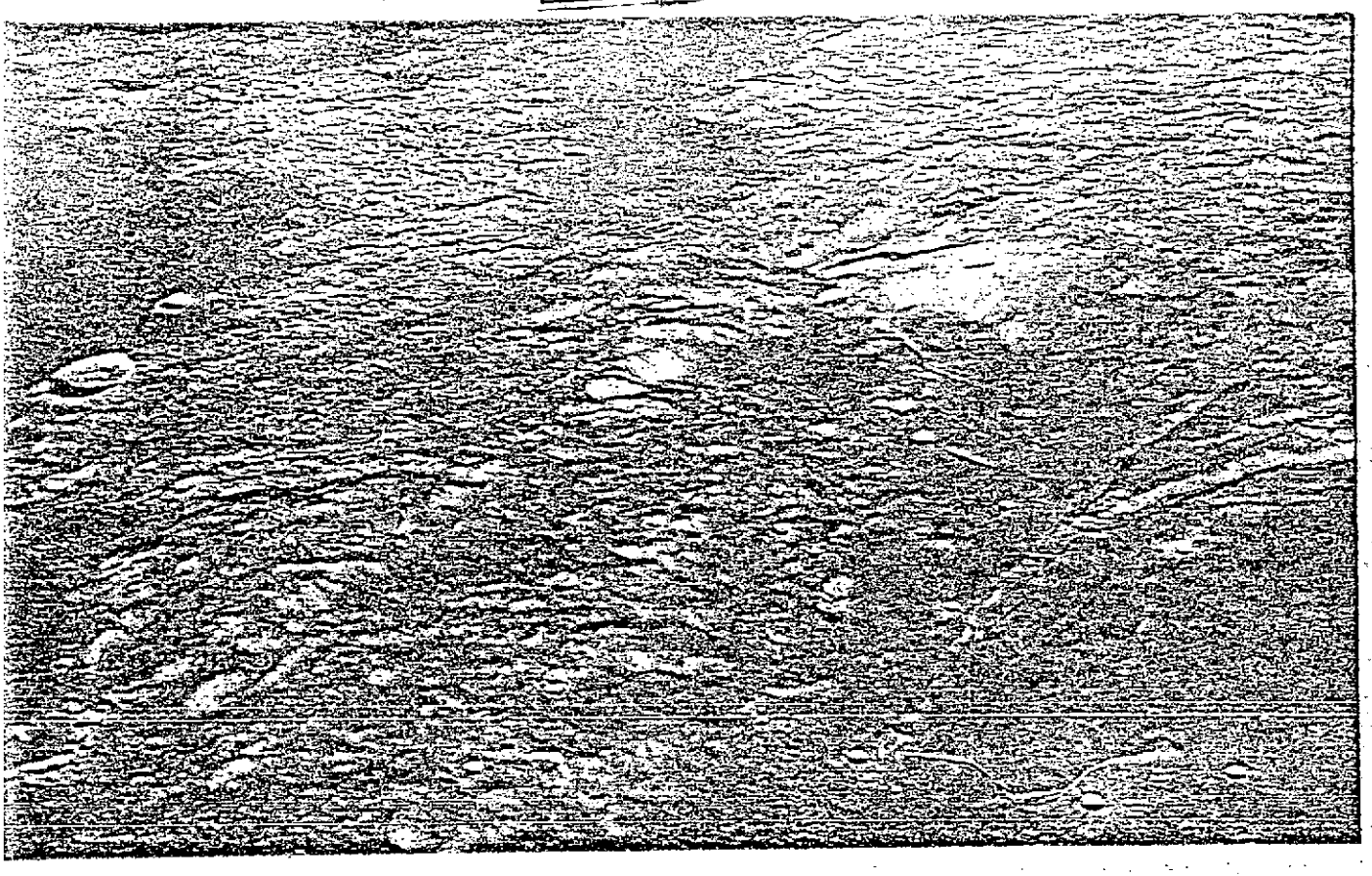

Figure 5

El-Baz : Observations of Mare Serenitatis