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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Apollo 8 Colorimetry

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DATE- March 11, 1969

FILING CASE NO(S)- 340

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ABSTRACT

The results of the two color CSM photographic experiment aboard Apollo 8 are discussed. Operational problems precluded obtaining data useful for data analysis by image processing.

The image processing technique applied to earth based lunar photography is discussed. A computer produced, color difference photograph is shown.

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I. INTRODUCTION

Apollo 8 presented a unique platform from which to perform high resolution lunar colorimetric photography. All previous spectral reflectivity or color measurements, with the exception of Surveyor,[1] have been made from the earth where even good atmospheric seeing limits resolution to approximately 1 km at the lunar sub-earth point. No backside color measurements had been undertaken previously.

Lunar color has been a long standing interest of planetary astronomers. Recently, a number of investigators have attempted to interpret color differences as due to differences in particle size,[2,3] age,[4,5] or composition.[6,7] McCord[7] makes a strong argument in favor of compositional differences being the cause of color differences based on the results of an exhaustive series of differential photometric measurements.

If subsequent evidence proves the correlation between spectral reflectivity and composition, and sufficient "ground truth" can be obtained, accurate high resolution color measurement will be an extremely useful tool in geologic mapping of the lunar surface.

Photoelectric photometry is the most accurate means with which to make spectral reflectivity measurements. Accuracies of 0.1% are obtainable.[7] However, at the present time, photometry is a slow, point for point method, not suitable for large areal coverage or convenient data display. With some sacrifice in accuracy, photographic methods can be employed. Using microdensitometry, photographic plates can be analyzed for quantitative color differences, but again data display is difficult and the method is time consuming. Telescopic color difference pictures have been produced by Whitaker[8] which give qualitative color information in image form. In this method a print is produced from a sandwich of a blue negative and a red positive plate. Color boundaries, particularly in mare regions, are easily detected. Errors are introduced because of the difficulty in accurately controlling the photographic development and reproduction processes over a wide dynamic range.

An image processing method has been developed to utilize the high information content and good display characteristics of photography and to circumvent the difficulties of standard microdensitometry, to obtain quantitative color information. Details of this method will be discussed below.

Study of differential color photometry[7] reveals that a large number of spectral curves, particularly in the mare regions, exhibit a nearly linear behavior in the wavelength region 4000-7000 Å. Therefore, the greater the wavelength separation of the points in the spectrum observed, the greater the difference signal obtained. Typical differences obtained across color boundaries in the maria, after albedo normalization are 4 to 7%. Such color differences are not detectable by the eye or on color film without special enhancement techniques.

II. APOLLO 8 COLOR EXPERIMENT

The design of the Apollo 8 two-color experiment was largely dictated by hardware and mission constraints. Color separation photography on black and white film was the only feasible method for obtaining quantitative color information from orbit. Two filters were chosen to give the greatest wavelength separation commensurate with spacecraft window transmission and film sensitivity constraints. The filters, 47B (dominant wavelength 4530 Å) and 29 to .6ND (dominant wavelength (6330 Å) were mounted in a slide device which attached to the lens in place of a filter. Exposures were made alternately through each filter. The time between exposures was less than 5 seconds. Using the Hasselblad camera and 80 mm lens, lunar surface resolution from orbit was expected to be 50 m or approximately 20 times greater than the best earth-based telescope photography.

III. DATA RETURN

For operational reasons, no scheduled target of opportunity photography, including red-blue filter photography, was carried out in the 9th orbit. At this time the filter holder was used to reduce the light level in the TV camera. After transearth injection (TEI), a number of red-blue photographs were taken. All were taken with the 250 mm lens. Accidently, 33 exposures were made on SO 368 (color) film and were, therefore, not usable for analysis. Unfortunately, these were the best exposures made, as the images filled almost the entire frame. Shortly after TEI, 8 pairs of red-blue photographs were exposed on 2485 high speed film. This film had been intended for dim light photography but was exposed according to the plan for 3400 film. Thirteen exposures were also made using the polarizing filters. No exposure calibration was made before processing the 2485 magazine.

Therefore, no quantitative color data can be retrieved from these images. Further attempts will be made to recover some qualitative color information since backside areas are included in the images. Magazine E of 3400 film contains 10 pairs of red-blue exposures. However, the full moon, quarter phase images measure only 8 mm in diameter or less, making them unsuitable for analysis.

IV. IMAGE PROCESSING

The requirement for reducing a large number of color separation photographs to obtain high resolution quantitative color data precluded the use of standard microdensitometry methods.

The Jet Propulsion Laboratory Image Processing Laboratory, under the direction of F. C. Billingsley, offered to assist in the analysis of Apollo 8 two-color photography. The process is a variation of routines used in the analysis of other types of photography.[9,10,11]

In order to develop and test the method, telescope photographs of several lunar areas were taken through a rendezvous heat shield window and the appropriate filters. Film and processing were identical to that used on the flight. Sensiometric calibration strips were pre-exposed through the same filters.

Both the film and the calibration strips were digitized with a scanning spot size of 25μ. A 10,000 pixel (picture element) sample of each calibration step was scanned. Plots of the DN (digital number) versus density of the initial exposing wedges produced overall system calibration curves (DN vs. log E) for each of the filters.

Each picture was scanned several times and the multiple scans averaged to minimize noise. Subsequently, a geometric correction program was used to register the red and blue pictures to each other. These became the master input pictures for the processing.

Each picture was then converted to the log exposure domain through application of the appropriate calibration curve to each pixel, after which the relative exposure between pictures was adjusted to give an equal DN in each picture in an area defined to be gray by observation. Subtraction of one picture from the other is the equivalent of taking the ratio of the exposures, resulting in a "picture" independent of overall albedo differences, whose negative values represent varying shades of one color, zero represents gray, and positive values represent the other color. The colors are progressively more intense as the DN departs from zero.

Figures 1 and 2 are the original scanned 47B and 92+0.6 ND (dominant wavelength 6460 Å) photographs respectively. Plato, Sinus Iridum and a portion of Mare Imbrium are visible. Figure 3 is the difference picture in which the light areas are blue and the dark areas are red. The differences have been expanded to nearly fill the dynamic range of the processor. A point known as Plato E[7] was chosen to be gray.

The major color boundary in Mare Imbrium has been measured photoelectrically.[7] A color difference of 5.5% ± 0.5% was measured across the boundary at the points Mare Imbrium 3 and 4. The corresponding difference found by image processing is 5% ± 2.5%.

Other methods of data display such as two color printing and color-difference contouring are planned. A complete discussion of this method will be published elsewhere.

V. SUMMARY

A two-color photographic experiment was flown on Apollo 8. A number of exposures were made but operational requirements did not allow for the planned target-of-opportunity photography in lunar orbit. Exposures made after transearth injection were not suitable for analysis except possibly for frames on high speed 2485 film. Computer image processing techniques have been developed for obtaining quantitative color imagery from color separation photographs such as those taken on Apollo 8. The two color experiment should be flown on subsequent lunar flights to obtain high resolution imagery for use in geologic mapping.

ACKNOWLEDGEMENTS

I wish to thank Dr. Bruce Murray for suggesting this type of experiment, and in particular, Mr. Sol Giles of the California Institute of Technology for aid in the design of the filter holder and for the manufacture of the devices on very short notice. Mr. Jurrie van der Woude gave excellent assistance in the photographic testing program.

2015-AFHG-kse

A. F. H. Goetz

Attachments
Figures 1 to 3

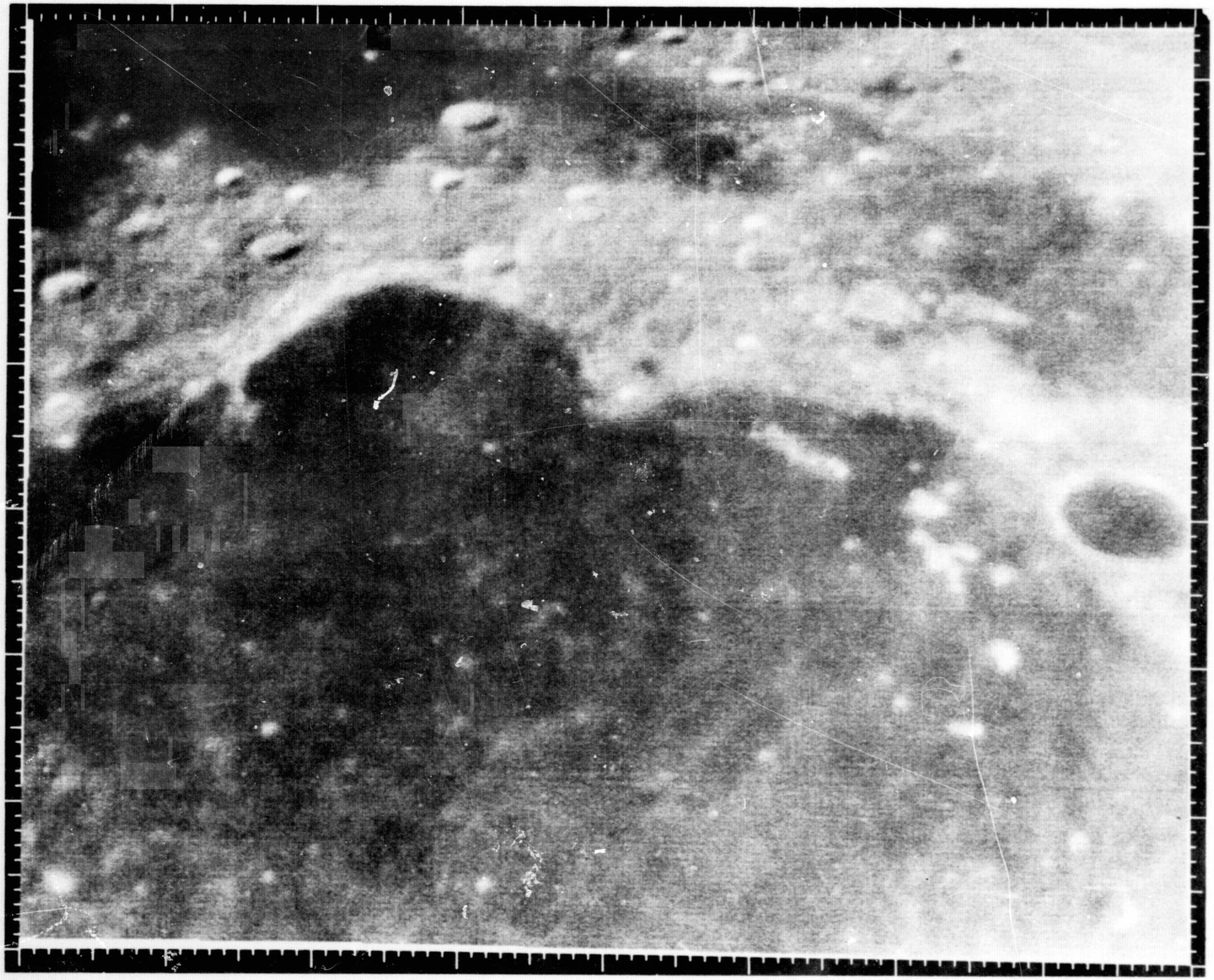

FIGURE I - MARE IMBRIUM INCLUDING PLATO AND SINUS IRIDUM. TAKEN ON MT. WILSON 24 IN. TELESCOPE THROUGH AN APOLLO SPACECRAFT HEAT SHIELD WINDOW AND 47B (BLUE) FILTER. 35MM 3400 FILM WAS USED. THE ORIGINAL NEGATIVE WAS SCANNED WITH A 25μ SPOT SIZE AND THE TAPE REPLAYED TO PRODUCE THIS PHOTOGRAPH

FIGURE 2 - SAME AS FIGURE 1 EXCEPT TAKEN THROUGH A 92 + 0.6ND FILTER

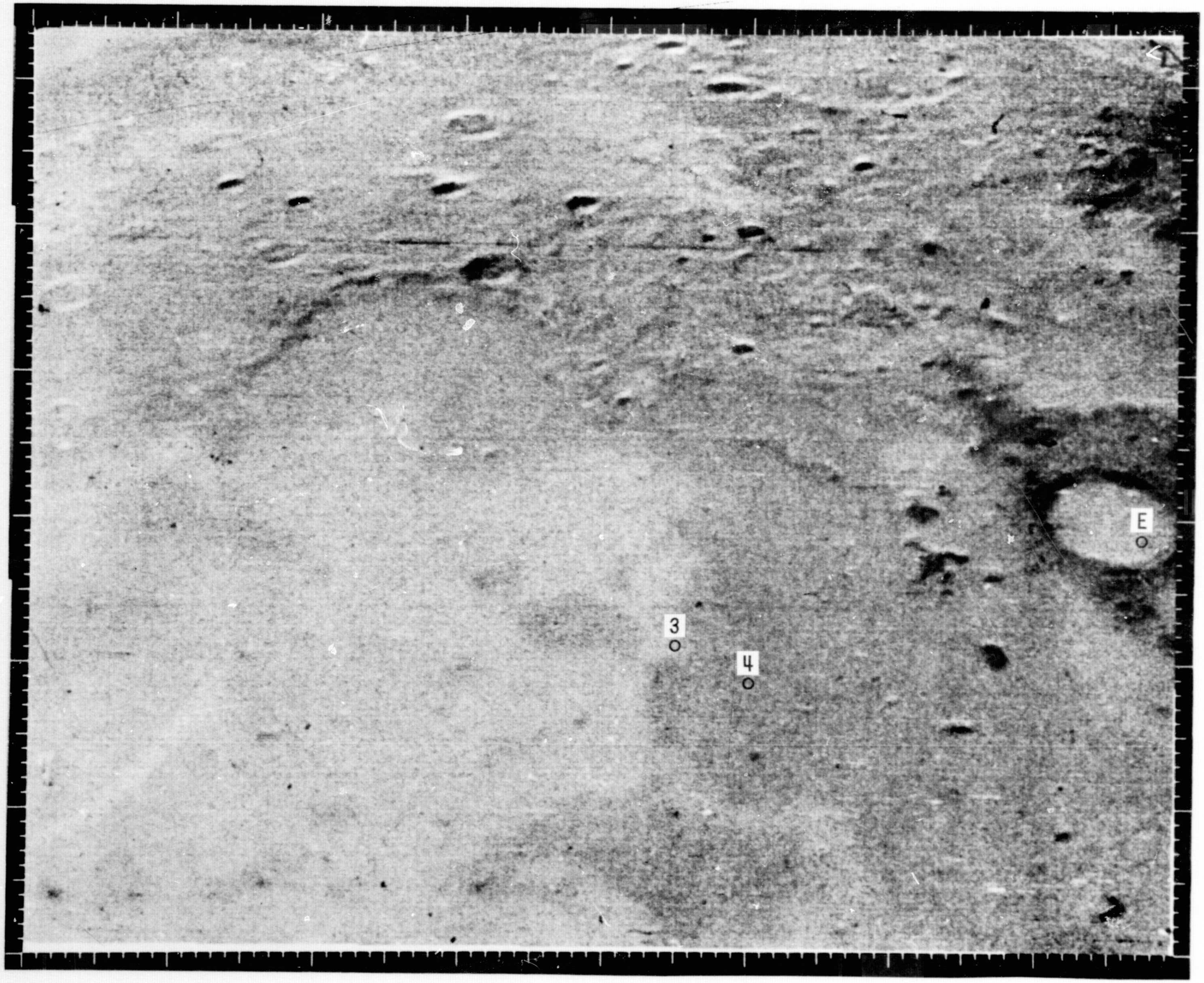

FIGURE 3 - BLUE MINUS RED DIFFERENCE PICTURE IN WHICH LIGHT AREAS ARE BLUE AND DARK AREAS ARE RED. BOUNDARIES EXHIBITING UNIFORM COLOR IN SPITE OF ALBEDO CONTRASTS, SUCH AS THE EASTERN RIM OF SINUS IRIDUM, DEMONSTRATE THE DYNAMIC RANGE AND GOOD REGISTRATION ACHIEVED

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