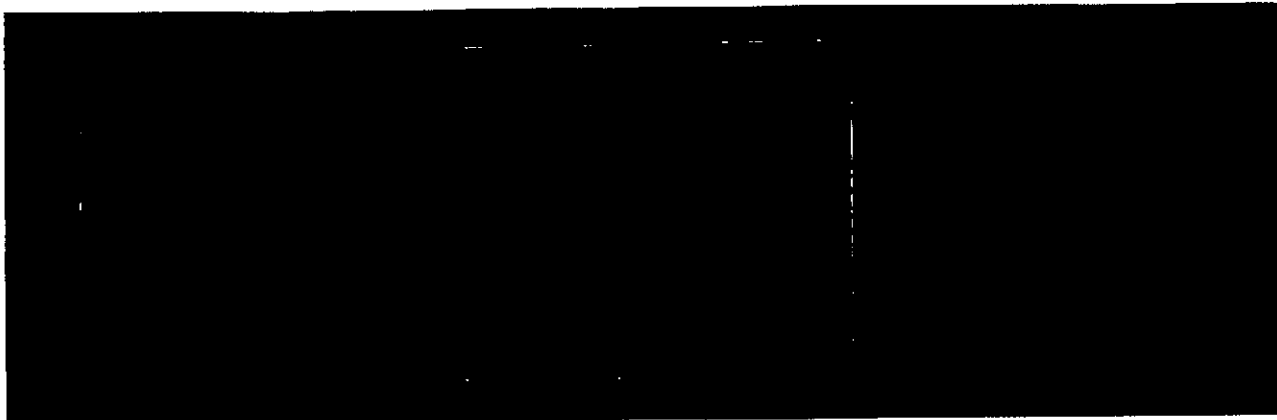


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1 April 1974

Photographic Techniques
for Enhancing ERTS MSS Data
for Geologic Information

William Geluso

Robert Anderson

Principal Investigator: Edward Yost

Final Report

covering the period January 1973-March 1974

**COLOR ILLUSTRATIONS REPRODUCED
IN BLACK AND WHITE**

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Center, Greenbelt, Maryland 20771.

ORIGINAL CONTAINS

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**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

Table of Contents

<u>Section</u>	<u>Title</u>	<u>Page</u>
1	INTRODUCTION	1
2	MULTISPECTRAL TECHNIQUES	3
	Additive Color Techniques	3
	Isoluminous Technique	5
3	PHOTOGRAPHIC ANALYSIS OF ERTS IMAGERY	13
	Processing of Black-and-White ERTS	13
	MSS Imagery	17
	Isoluminous Additive Color	23
4	GEOLOGIC ANALYSIS	26
	Geological Contacts in the Basins	26
	Geological Contacts and Faults in the	27
	Ranges	29
	Pediments as Seen on Additive Color	29
	Photographs	31
	Visual Comparison of Additive Processes	31
	REFERENCES	33

Section 1

Introduction

Based upon the experience in analyzing S065 multispectral space photography, data analysis techniques were developed for efficiently transforming Earth Resources Technology Satellite MSS imagery into useful geologic earth resources information. Earth Resources Technology Satellite (ERTS) was successfully launched on 23 July 1972 and placed into a nominal orbit by the Delta Launch Vehicle. Adjustment was done to correct the orbit to the eighteen-day repeat cycle. Multispectral Scanner (MSS) imagery was acquired every eighteen days over a particular geographical area in four different regions of the spectrum. The spectral bands included the 500-600 nm, 600-700 nm, 700-800 nm, and 800-1100 nm regions.

Before the launch of ERTS, only a few limited studies have evaluated the geological utility of space photographs covering the southwestern United States (Lowman, 1969; Titley, 1968; Amsbury, 1969). The Apollo 9 experiment (S065) was the first attempt to obtain multispectral photography of the earth's resources from space. The initial results of this experiment clearly demonstrated the value and feasibility of multispectral photography from orbiting spacecrafts for geological studies (Lowman, 1969).

Presented in this report are the photographic techniques developed to aid the geologic discipline in reducing ERTS MSS data. These techniques include the photo processing methods, conventional additive color

viewing techniques, direct projection methods, and isoluminous additive color techniques. Two MSS frames (E-1388-17154 and E-1406-17152) imaged by the Earth Resources Technology Satellite on 15 August and 2 September 1973 over Luna County, New Mexico, were employed for developing the above-mentioned techniques. The study was supported under Grant NGR-33-151-006 by Goddard Space Flight Center, Greenbelt, Maryland. Also included in this report are observations made by visually analyzing the two sets of multispectral additive color and isoluminous photographs for the geological data contained therein.

Section 2

Multispectral Techniques

Spectral Data Model 64 additive color viewer was an essential instrument used for analysis of ERTS MSS data obtained over Luna County, New Mexico. The Model 64, shown in Figure 1, can be used as a direct projection or as a viewer for the purpose of viewing MSS 70mm chips in any of the photographic formats - a synthesis of two, three, or four multispectral images of multiband photographic data in true color, false color, or black-and-white.

Using the additive color viewer, conventional multispectral techniques have been successfully employed to analyze photographic data from aircraft altitudes for the detection and identification of certain classes of environmental phenomena (Yost and Wenderoth, 1967).

Additive Color Techniques

Two methods were used to produce the non-isoluminous additive color renditions utilized for geological interpretation in this report.

A. Linear Reproduction. ERTS multispectral images were placed into the additive color viewer shown in Figure 1. The desired rendition was achieved on the rear-projection screen of the additive color viewer and the screen was photographed on color negative film (4 x 5" Ektacolor Type L). The negative image could then be enlarged to the desired scale. By this method, an unlimited number of additional copies, at any reasonable scale, can be made at any time.

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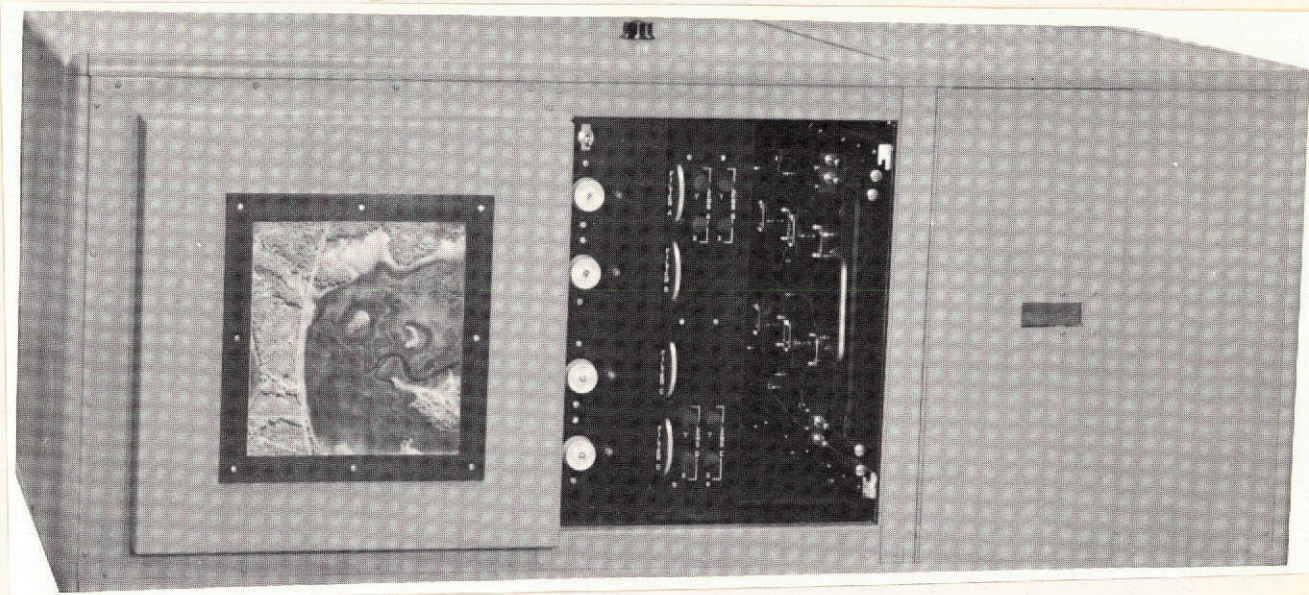


Figure 1. Spectral Data Model 64 viewer used in the analysis of ERTS data.

B. Direct Projection. In this technique, the additive color viewer is used as a projector. The ERTS MSS images are enlarged to the desired scale and registered to each other on a reflection (rather than a rear-projection) screen. The relative brightness of the three images is adjusted to yield the most ideal representation of the terrain. The screen is then replaced by a reversal color paper (Kodak Ektachrome RC paper, Type 1993). The paper is sequentially exposed to the three images, utilizing filters chosen to match the sensitivity of the three dye layers of the paper.

The advantages of this technique, over photographing the screen, are:

1. Better resolution and registration due to elimination of

the recording optics, the screen and mirror of the viewer, and the color negative.

2. Better reproduction of subtle color differences due to elimination of the subtractive color film used for the intermediary negative.

The disadvantages of this technique are as follows:

1. Once the desired scale is set, additional images at other scales cannot be produced without a time-consuming procedure.
2. Additional images cannot be produced at a later date, except by repeating the initial procedure.
3. The number of copies that can be made initially is limited by the fact that the time required for exposure and processing of this paper is much greater than that used in printing a color negative.

Because of these disadvantages, only a section of the additive color renditions produced by direct projection are included in this report.

Isoluminous Technique

This technique has the advantage of both emphasizing subtle spectral differences between bands by greatly enhancing the color of the superimposed composite of all bands and eliminating the effects of brightness caused by sloping terrain and shadows. The technique is useful in detecting subtle environmental spectral differences under dynamically changing illumination, such as often encountered in vegetation and soil mapping in areas where the topography is variable.

Conventional photographic techniques, black-and-white or subtractive color films, associate image density with the brightness of the object. Similarly, in the conventional additive color display of multispectral photography, a positive color space is presented in which the brightness of the color image (not necessarily the chromaticity of the image) increases as a function of increasing brightness in the original scene. The exact relationship depends on the characteristic curves of the individual spectral bands used.

It is evident in the multispectral black-and-white photographs, as well as in the associated additive color renditions, that large brightness differences in the terrain frequently prevent detection of subtle spectral differences between objects when they differ considerably in brightness.

An isoluminous multispectral composite photograph is one in which all objects in the scene are presented at the same brightness level. Hence, all color differences which appear on the isoluminous multispectral photograph relate to differences in the spectral distribution of the terrain. Isoluminous displays are generated from a standard set of multispectral negatives using a photographic masking process.

In order to illustrate the isoluminous procedure, a hypothetical set of characteristic curves of the blue (B), green (G), and red (R) negatives are shown in Figure 2 on the following page. The x-axis represents the log intensity of the image-forming light and the y-axis the corresponding density. The gamma of the three negatives is the same and the black, gray, and white objects will, naturally, image as the same density on each negative. An object (labelled as "o" on the x-axis)

which has color will exhibit a difference in the intensity of the image-forming light in each spectral band. This results in a different density in each of the three negatives denoted as D_1^0 , D_2^0 , and D_3^0 respectively.

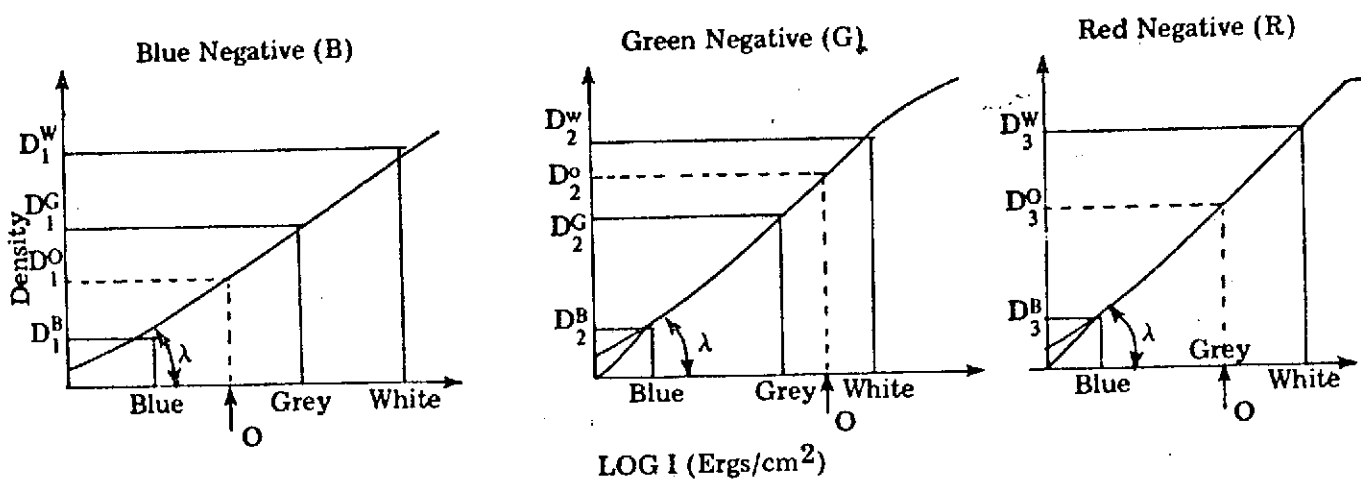


Figure 2. Characteristic curves of the red, green, and blue multispectral negative.

Initially, the characteristic curve of each multispectral record or band is examined and the straight line portions are defined. Two achromatic or gray areas on the imagery (one in the highlights, D_{max} , and one in the shadows, D_{min}) are selected for brightness normalization. That is, these areas represent the range of densities which will be reduced to a common value in the final presentation. Small circular neutral density "chips" which exactly match the D_{min} and D_{max} values may be reproduced along

with the image in each of the processing steps. These chips will eliminate the difficulty associated with locating the exact "highlight and shadow" image areas for subsequent processing measurements. The only constraints placed upon the selection of the D min-D max areas is that both points must lie along the straight lines of the characteristic curves and the brightness ranges, $\Delta \log E$, of each set must be almost identical. This latter condition assures that the two areas are truly achromatic.

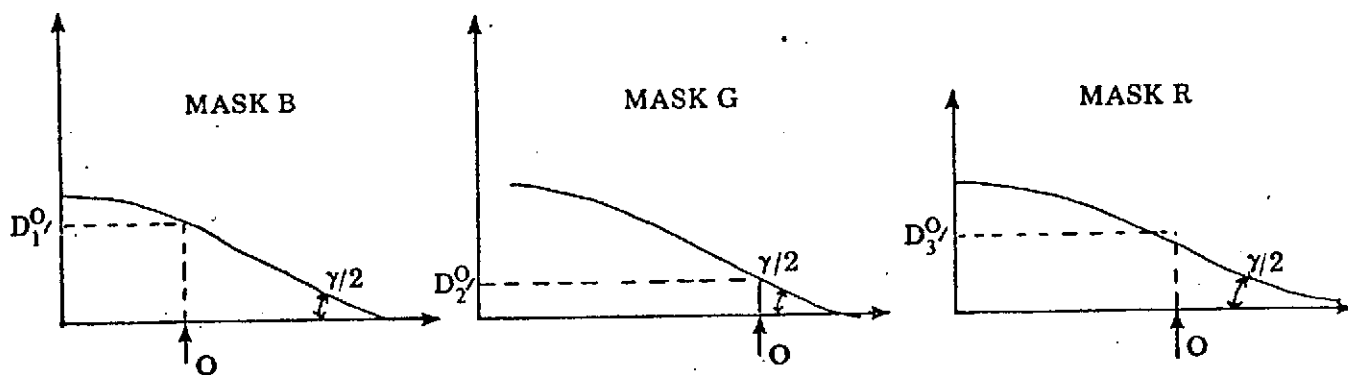


Figure 3. Characteristic curves of half gamma masks produced from multispectral negatives.

The second step of the process, shown in Figure 3, consists of producing a half gamma positive mask of each record in which the density range of the positive is only 50 percent of its corresponding negative. Verification of this desired density range is easily made by measurement of the D min-D max chips off the positive masks. The negative of each multispectral record is then registered together with the two positive masks

of the other bands to form friskets of three films each. For example:

<u>Negative</u>		<u>Positive 1/2 Gamma Mask</u>
Blue	plus	Green and Red
Green		Blue and Red
Red		Blue and Green

Precise exposure control is required for the accurate photometric printing of the positive masks.

The density relationships of the three negative-positive mask combinations are shown in Figure 4 on the following page. The horizontal line corresponds to the linear relationship of the brightness for any colorless object lying on the straight line portion of the characteristic curve. The density of object "o", however, is different on all three masked positives.

To summarize, the masking technique which is required to produce the isoluminous image is diagrammed in Figure 5. The sequence is as follows:

1. For a given frame, three spectral photos are selected for additive color viewing.
2. From each of the three spectral negatives, a 50 percent positive mask is made by contact printing. The density range of a 50 percent mask is 50 percent of the density range of the negative which produced it.
3. Each negative, in turn, is mounted in register with the two masks produced from the other two negatives, and a masked positive is printed for viewing.

In obtaining isoluminous color renditions from positives, all density differences represent hue and saturation differences only. When such a set of multispectral masked photographs are projected in an additive color

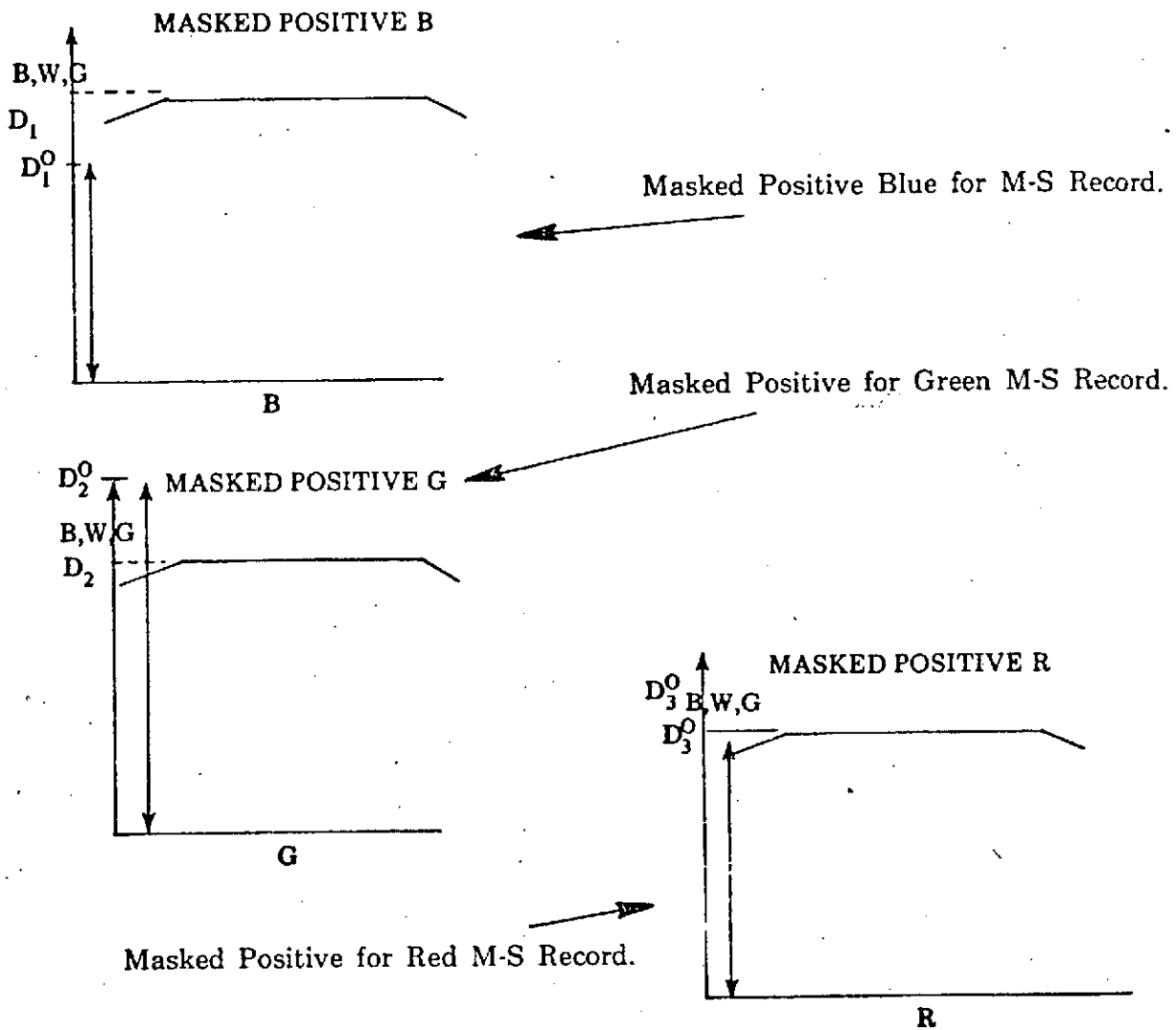


Figure 4. Characteristic curves of negative half-gamma positive mask combination.

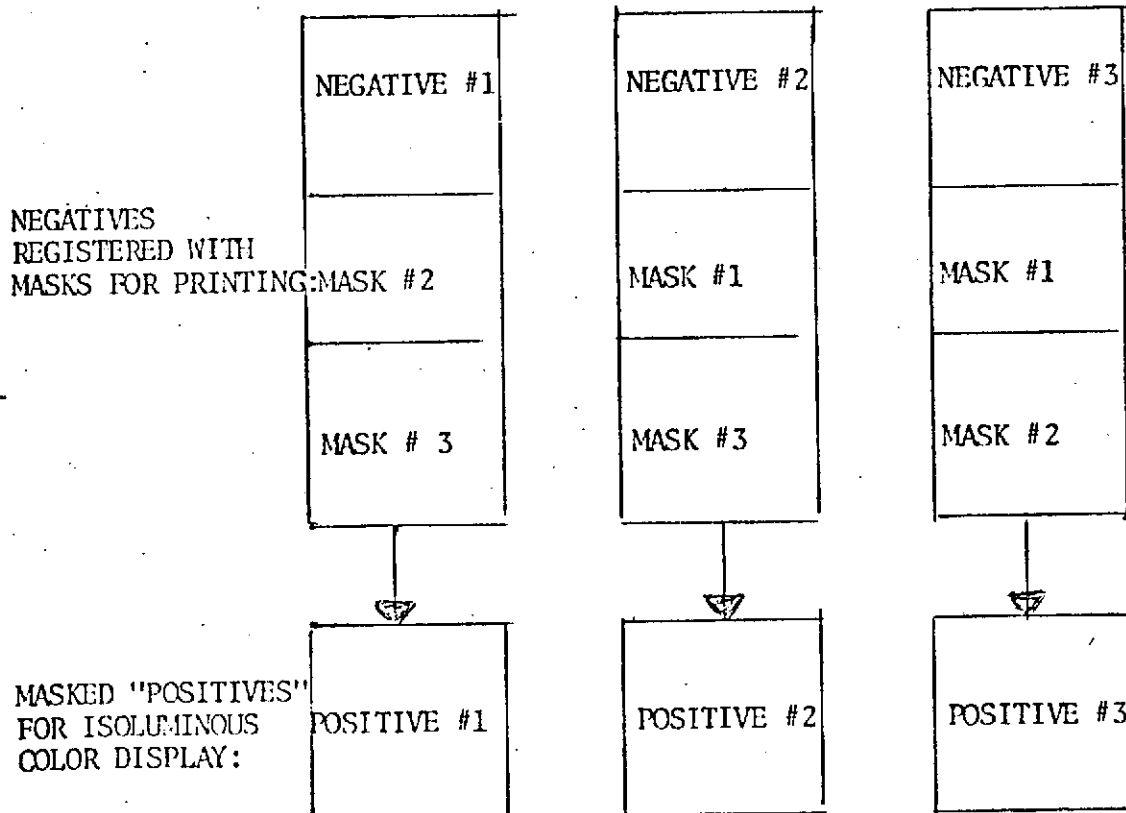
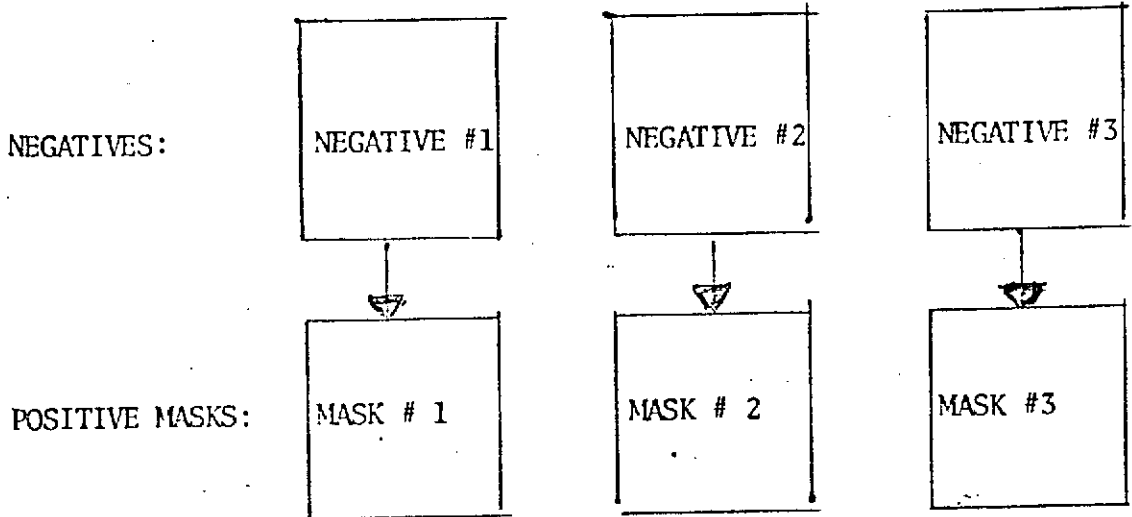


Figure 5. Masking procedure for isoluminous multispectral additive color displays.

viewer, using any combination of filters to generate a particular color space, a display which is "isoluminous" will be formed. In this type of display, all achromatic (colorless) objects are projected at a fixed brightness level. Any colored object will also be projected at this same brightness level. Strictly speaking, an isoluminous display of this type is neither negative or positive since such terms are applied to the ordering of image brightness.

Section 3

Photographic Analysis of ERTS Imagery

Photographic analysis of ERTS MSS data was performed using multi-spectral techniques, both conventional and isoluminous. Two sets of ERTS frames were acquired by the Earth Resources Technology Satellite over Luna County, New Mexico. Frame E-1388-17154 was imaged on 15 August 1973 and frame E-1406-17152 was photographed on 2 September 1973. A set of four ERTS MSS images for 2 September 1973 is shown in Figure 6.

Processing of Black-and-White ERTS MSS Imagery

In order to investigate the visual effect in the isoluminous image of expansion of the color space, the two sets of positive images were used in the additive color viewer. The release positives of 15 August 1973 (E-1388-17154) imagery were used for both normal additive color and isoluminous additive color. The release positives are gamma "one" positive reproductions of the negative. A three-color additive rendition of any three of these positives, balanced to yield the data block wedge as a neutral gray, may be considered to be a linear, one to one, rendition of the spectral reflectance of the original scene. Figure 7 shows the relationship of positive density to negative density for the release positive of band 6 for 15 August 1973. The gamma "one" linearity can be seen to extend from step 2 (high density in the positive) to step 15 (low density in the positive) for 15 August 1973.

Previous experience with additive color projection of multispectral imagery has shown that higher color saturation, and therefore greater color discrimination, can generally be achieved by expansion of the

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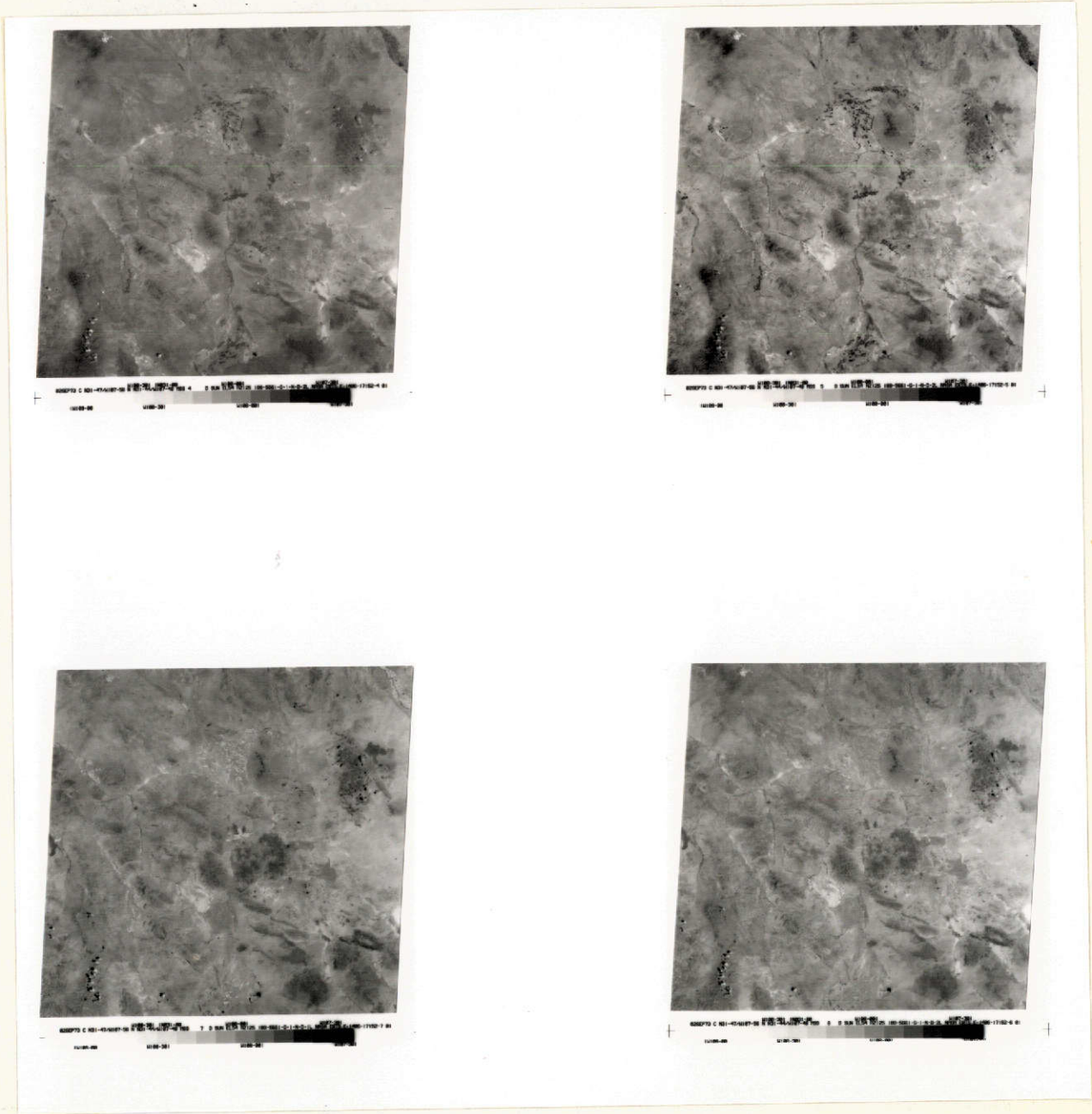


Figure 6. A set of four ERTS MSS images for 2 September 1973 (E-1406-17152). Band 4 represents the 500-600 nm spectral region, band 5 the 600-700 nm region, band 6 the 700-800 nm region, and band 7 the 800-1100 nm region.

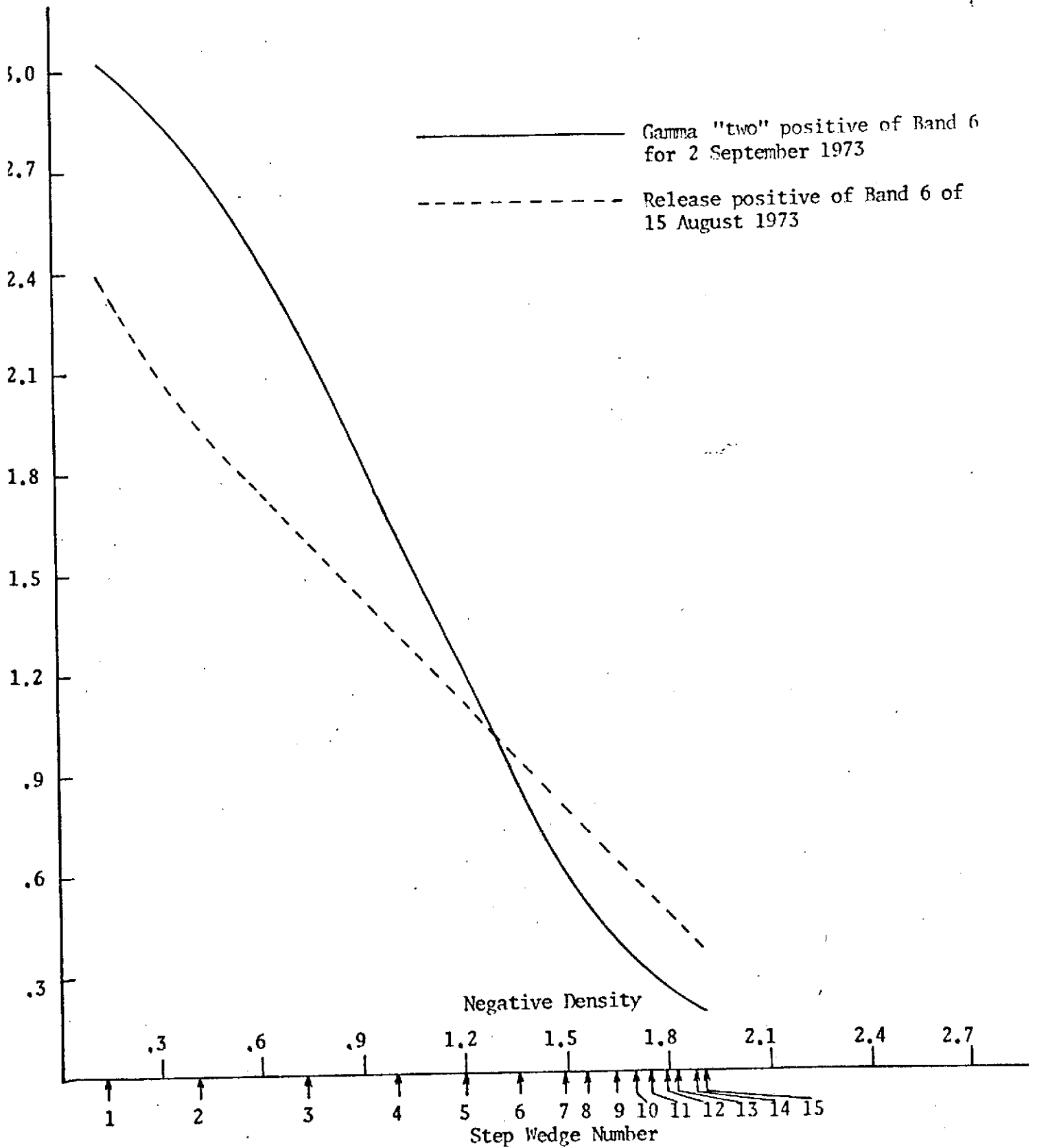


Figure 7. The relationship of positive density to negative density for the release positive of band 6 of 15 August 1973 and for the gamma "two" positive of band 6 for 2 September 1973.

density range of the positive image. Increasing the density range of the positive reduces the brightness range of the scene that can be accommodated in the straight line (linear) portion of the curve. The exposure of the positive image must therefore be carefully controlled in order to place the areas of interest within the image onto the straight line portion of the curve.

Gamma "two" positives were printed from the 2 Sept. 1973 (E-1406-17152) negatives. This positive imagery was used for both normal additive color and isoluminous additive color. The relationship of positive density to negative density for the band 6 gamma two positive of 2 Sept. 1973 can be seen in Figure 7. An examination of this curve shows that the linear portion extends from approximately step 3 to step 9. Densitometric measurement made in several areas of the image indicated that most of the image area fell within this density range.

Due to the apparently high clarity of the atmospheric column at the time this imagery was recorded, no differential processing was required within each set of four MSS images. Whenever haze is present, the atmospheric scattering of the shorter wavelengths, particularly in band 4 (500 - 600 nm), compresses the density range of the image, but not of the step wedge in the data block. This compression of the image density range can be compensated for, within limits, by differentially processing the positives to make a set of positives that are balanced in density range in terms of the images. When this is done, the data block step wedge will never be monochromatic in an additive color rendition.

Gamma "two" positives of 2 Sept. 1973 MSS image were placed into the Spectral Data Model 64 viewer and the spectral records were projected

as follows:

500-600 nm Band - Blue
600-700 nm Band - Green
800-1100 nm Band - Red

Only one of the infrared bands was projected with the two visual bands and the composite color image was viewed on the screen. The screen reproduction is shown in Figure 8. The reproduction was made by photographing the screen of the additive color viewer with color negative film. Figure 9 is a direct projection of 15 August 1973, utilizing gamma "one" release positives. Figure 10 is a direct projection of 2 September 1973, utilizing gamma two positives. In both cases, band 4 is projected as blue, band 5 as green, and band 7 as red.

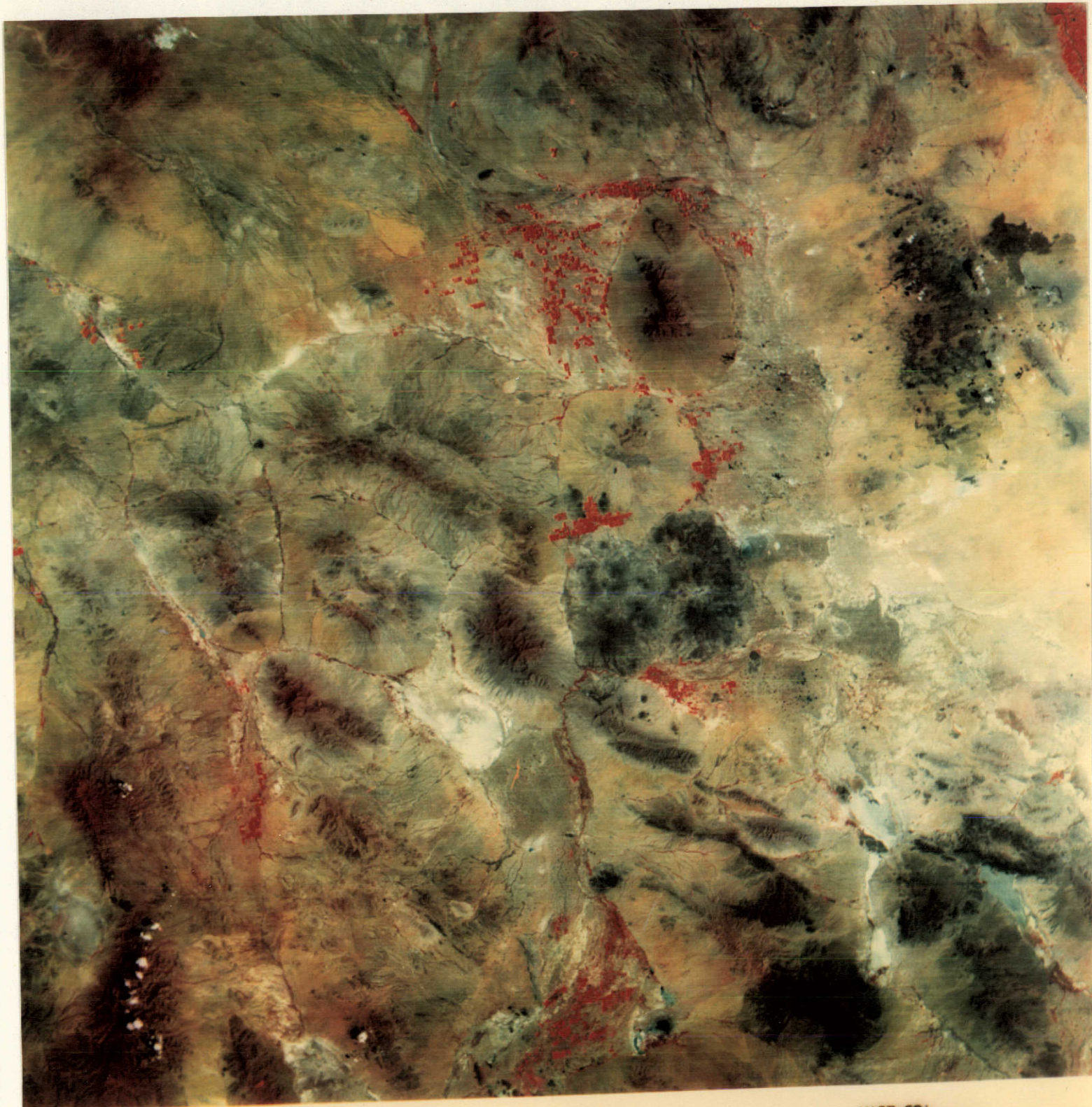
Isoluminous Additive Color

The direct projection technique was used to produce the isoluminous rendition used for geological interpretation. The isoluminous process is a masking process which removes brightness differences from the final image, leaving only color differences. A detailed discussion has been presented in Section 2 of this report. This brightness cancellation can be achieved only in areas which are linearly reproduced throughout all intermediate steps. As was stated previously, most areas within the images fall within the density range represented by steps 3 to 9.

Two isoluminous images have been produced for geological interpretation in this report. Figure 9 utilized gamma "one" release positives of 15 August 1973. Figure 10 utilized gamma "two" positives of 2 September 1973. In both, band 4 was projected as blue, band 5 as green, and band 7 as red. The degree of brightness cancellation can be seen by examining

the step wedge of the data blocks. Steps 3 and 9 are indicated by arrows.

The process by which the final isoluminous image was produced was developed experimentally for this report. It is a simplification of the existing process and is the first time that the isoluminous process has been applied to ERTS MSS imagery. In this modification, a single mask is utilized. This mask is an effective gamma "one" negative composite image of the three bands being projected. It is placed in the aerial image plane, in register with the aerial image, and in contact with the color paper during exposure. By utilizing only one mask, rather than three masks in the original development of the isoluminous process, a greater degree of resolution is retained in the final isoluminous image.



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N N31-44/W107-48 MSS 45 7 D SUN EL54 AZ125 189-5661-G-1-N-D-2L NASA ERTS E-1406-17152-8 01
W108-001 W107-301

Figure 8. A screen reproduction utilizing gamma "two" positives of 2 September 1973. Band 4 is projected as blue, band 5 as green, and band 7 as red.

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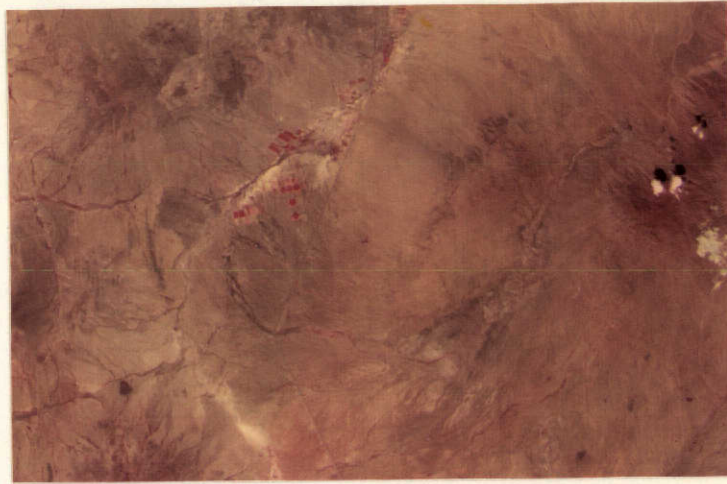


Figure 9. A section of a direct projection utilizing gamma "one" release positives of 15 August 1973 imagery. Band 4 is projected as blue, band 5 as green, and band 6 as red.

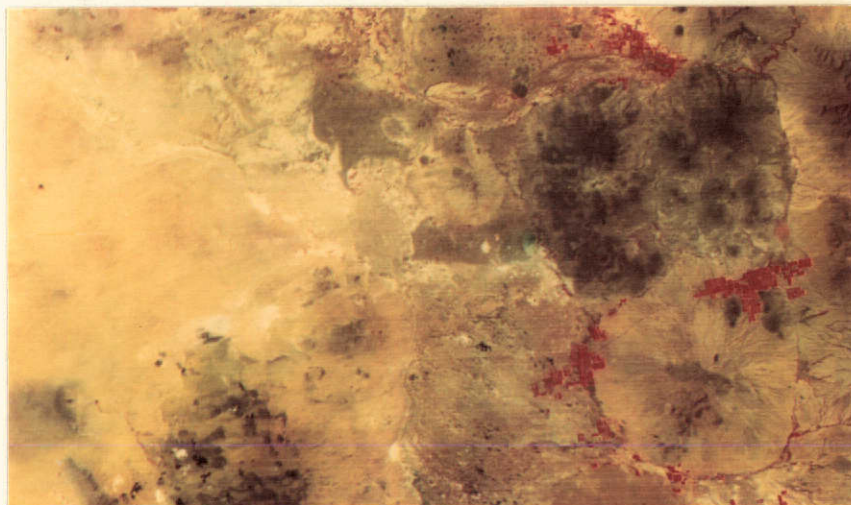



Figure 10. A section of a direct projection utilizing gamma "two" positives of 2 September 1973 imagery. Band 4 is projected as blue, band 5 as green, and band 6 as red.



Figure 11. An isoluminous direct projection utilizing gamma "one" release positives of 15 August 1973 imagery. Band 4 is projected as blue, band 5 as green, and band 7 as red. The isoluminous process removes brightness differences from the image, leaving only color differences.

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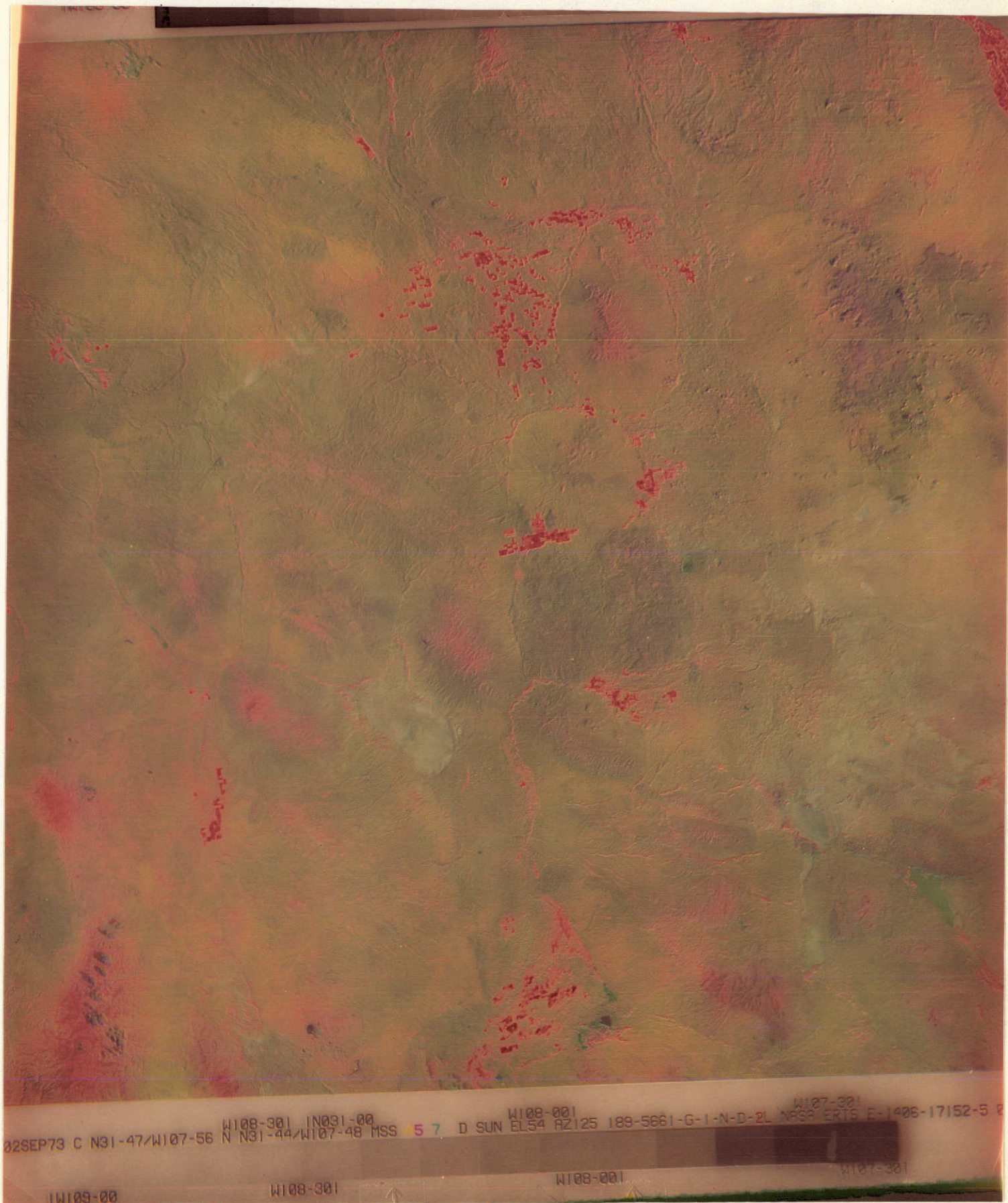


Figure 12. An isoluminous direct projection utilizing gamma "two" positives of 2 September 1973. Band 4 is projected as blue, band 5 as green, and band 7 as red.

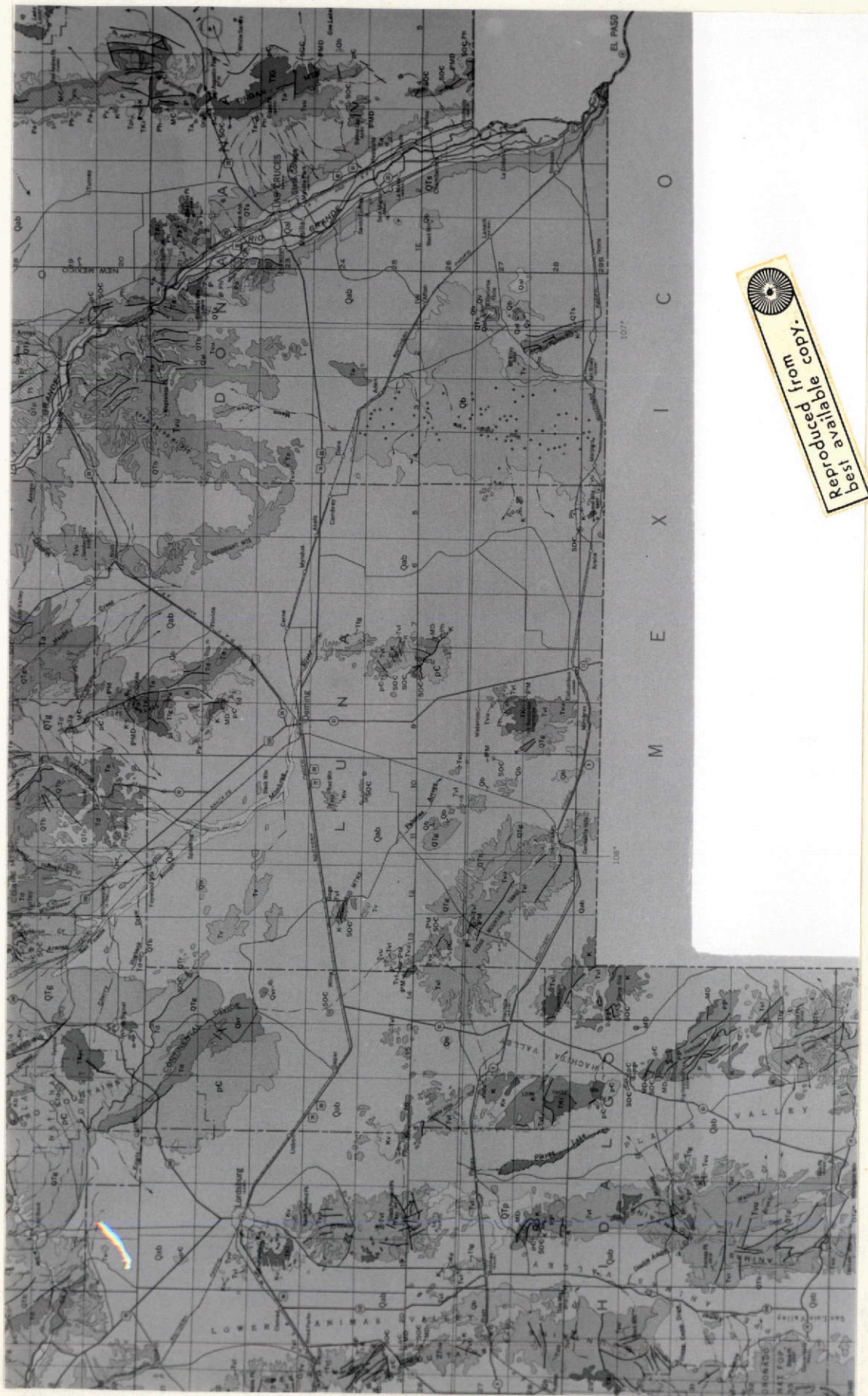
Section 4

Geologic Analysis

The isoluminous process, as well as other multispectral analysis techniques, were applied to two frames of ERTS MSS imagery (E-1388-17154 and E-1406-17152) acquired over Luna County, New Mexico in order to determine whether these techniques would enhance geological features of the terrain. The isoluminous technique has the advantage of emphasizing subtle differences between multispectral bands by greatly enhancing the color of the superimposed composite of all bands and eliminating the effects of brightness caused by sloping terrain and differences in magnitude of reflectance (Figures 11 and 12). The area of southern New Mexico covered by the ERTS frames is shown in a portion of the 1965 state geological map of New Mexico (Figure 13).

Geological interpretation was done by visually analyzing two sets of additive color and isoluminous composites of ERTS MSS frames for the geological data contained therein. First, visual comparison of the additive color renditions with the state geologic map of New Mexico was made to determine which geologic features (contacts, faults, etc.) were visible on these images. Then comparisons were made among the individual additive color photographs to determine in which images the various features were more readily discernible.

For this comparison, only the area north of the national border - Luna County, New Mexico - was considered. The area analyzed lies entirely within the Mexican Highland section of the Basin and Range Province. Outline of lithologic units from 1965 state geologic map of New Mexico is shown in Figure 14.





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Figure 13. 1965 state geological map of New Mexico showing Luna County and adjacent areas.



Figure 14. Outline of lithologic units from state geological map of New Mexico (1965).

Geological Contacts in the Basins

The contacts between the basaltic lava flows and the surrounding materials are extremely noticeable. The basaltic flows show up everywhere on the additive color photographs no matter how small the occurrence. In the larger basaltic occurrence, such as in the West Potrillo Mountains, individual volcanic features (necks, plugs, vents, etc.) may be observed (Figures 11 and 12).

The malpais lava shows up as a very distinct feature in the additive color rendition. On the other hand, the malpais lava is not distinguished at all from the other lavas on the state geological map. Also, in this same area, there appears, from the color composite, to be basaltic occurrences which are not recorded on the state geological map. Thus, in this area, at least, the additive color images exhibit a more accurate record of basaltic occurrences than does the state geological map.

The contact between the Santa Fe rock group and the general alluvium along the Rio Grande River is remarkably visible. Unfortunately, the ERTS MSS frame (Figure 8) shows only a very small segment of the Rio Grande. Since this contact is present along most of the course of the Rio Grande, south of Santa Fe, it would be interesting to see whether this contact shows up equally well on the adjacent ERTS frames showing the Rio Grande.

Where other bedrock protrudes from the alluvium, the contact between the bedrock and alluvium is visible in the ERTS additive color images. These isolated rock masses are termed inselbergs which are small remnants of larger mountain ranges and which have not, as yet, been eroded away. A statistical count of inselbergs per area gives an indication of what stage

in the geomorphic cycle an area is presently undergoing. Examples of such inselbergs, as seen from the additive color photos, are the Red Mountains and the Victoria Mountains. It must be noted that these inselbergs are also expressed in the topography. Some inselbergs develop miniature pediments around their base (Easterbrook, 1969). This inselberg/pediment relationship is clearly seen in the Grandmother Mountains.

The most recent alluvium, or overbank, deposits have a white visual signature on the additive color composite (Figure 3). These recent deposits occur mostly along the major streams and in the enclosed depressions of the area. When the photograph is examined, along with the two overlays, it is clearly seen that in some places the geologic map doesn't show these deposits whereas the photographs do. Therefore, as was the case with the basalt, the additive color imagery shows a more accurate record of the most recent alluvium than does the state geologic map.

Geological Contacts and Faults in the Ranges

There are several areas where the contact between the bedrock comprising the ranges and the surrounding alluvium is clearly visible. A good example of this is the Cookes Range. The south and west contacts are more clearly seen than the east contact. All of these contacts correspond to a steep topographic scarp.

One of the many NW-SE trending faults in the Big Hatchet mountains, for example, may be ascertained by the apparent split in the bedrock in the southeast portion of this range. It will be noted, however, that this location of faults by the visibly apparent displacement of bedrock is highly speculative. A quantitative analysis should be conducted across these features to determine whether the quantitative data can lessen the

speculativeness of a subjective interpretation.

Other visible contacts in the ranges are those between the latite and andesite volcanic rocks in the Alamo Hueco Mountains. The above are only a few examples of the contacts visible in the additive color images.

The Apollo 9 mission carried the multispectral terrain photography experiment (SO65) in which Luna County was photographed using different film/filter combinations in order to determine the feasibility and value of multispectral photography for earth resources studies. Visual comparisons of the pictures taken with different film/filter combinations were made for geologic information (Lowman, 1969). The comparison reveals that in the Tres Hermanas Mountains the contact between the andesite and rhyolite is clearly seen in the picture taken by using Panatomic-X film with red filter, but is hardly visible on the Panatomic-X/green filter combination. However, the contact between the Gila conglomerates and the rhyolite is better shown when using the green filter with the Panatomic film than the red filter with the film.

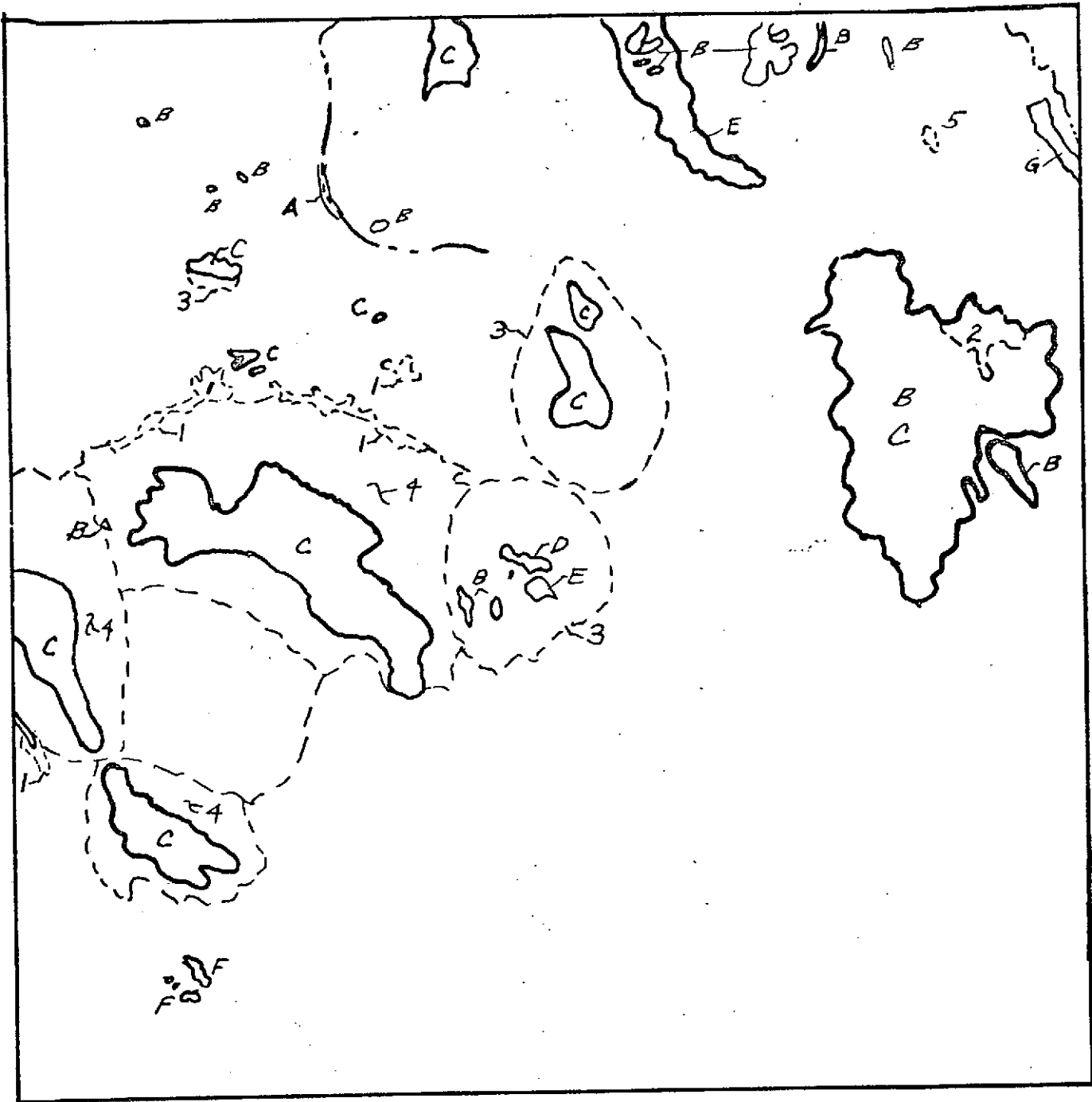
On the other hand, both of these contacts (andesite/rhyolite and Gila conglomerate/rhyolite) show up very clearly in additive color pictures. (There is more contrast between the andesite and rhyolite contact than between the rhyolite and Gila conglomerate contact. However, greater contrast is seen in the additive color pictures for the contact between the rhyolite and Gila conglomerate than by using Panatomic film with a green filter.) Therefore, additive techniques combine the advantages of using Panatomic film with a red filter and the advantages of using Panatomic film with a green filter. This combination of information into one format and, consequently, reduction in the amount of multispectral

data to be interpreted (Yost, 1967) is one of the objectives of applying multispectral data reduction techniques to ERTS imagery. Visual correlation of MSS color composites with the state geologic map was done for different geological features. Certain features which were seen by photographically enhancing ERTS MSS data did not appear on the state geologic map. An elementary sketch map of these geologic features is shown in Figure 15.

Pediments as Seen on Additive Color Photographs (Figures 8, 11, and 12)

It is realized that pediments are geomorphic rather than lithologic features and were, therefore, deliberately omitted from the state geologic map. However, these pediments show up strikingly on the additive color imagery.

Among all the pediments which are shown in the ERTS frames, the ones around the Florida Mountains and the Tres Hermanas Mountains are the most conspicuous. The circular lineations around these two pediments are described as pediment/bajada contacts (Lowman, 1969). The terms pediment and bajada are used in their strictly technical definition. An important question is raised as to whether these circular lineations are truly the contacts between pediments and bajadas because as seen from the ground, on air photos or topographic maps, there is no distinct boundary between pediments and bajadas (Easterbrook, 1969). One economic value of bajadas is that they contain large quantities of ground water. This ground water in bajadas is very easy to extract. Fresh ground water, especially in an arid region such as the Chihuahuah Desert of southern New Mexico, is a precious commodity.



GEOLOGIC FEATURES FROM MSS COLOR COMPOSITES

Correlations with State Geologic Map

Features not Appearing on Map

- A. Most recent alluvial deposits
- B. Basalt
- C. Bedrock/Alluvium contacts
- D. Latite
- E. Andesite
- F. Basaltic Andesite
- G. Sante Fe rock group

- 1. Most recent alluvial deposits
- 2. Malpais Lava
- 3. "Pediment" outlines
- 4. Piedmont slopes
- 5. Basalt

Figure 15. Sketch map of geological features as determined from additive color analysis of MSS imagery over Luna County, New Mexico.

Visual Comparison of Additive Processes

The various processing parameters, additive techniques, and reproductive techniques used here result in distinct differences in the final images. The suitability of each is dependent upon the interpretive purpose to which the images are applied. In visual terms, the following general statements may be made.

Direct Projection Vs. Screen Reproduction. A comparison of images produced by direct projection with those produced by photographing the viewer screen leaves no doubt to the superiority of the direct projection technique in terms of resolution of fine detail. This can be readily seen in the vegetative and structured patterns in the lower middle portion of the image. In terms of color, the screen reproduction tends to exaggerate color at the cost of some of the subtle color variations in the desert and mountainous areas.

Gamma 1 Vs. Gamma 2 Positive. In the screen reproduction, the gamma 2 positives have increased color differentiation within most of the image area, but the expansion of the brightness scale has resulted in a loss of detail in the regions of extremely high and low brightness. The same is true in the direct projection, but to a lesser extent. Here the increased color differentiation is evident with less detail lost in the brightness extremes. In the isoluminous images, where brightness has been eliminated in most areas of the image, the increased color differentiation is very helpful in distinguishing land masses.

Isoluminous Vs. Normal Additive Color. Because of the masking stages involved in the production of an isoluminous image, much fine resolution of structure is lost. However, the elimination of brightness differences due to such variables as the slope of the terrain in relation to solar angle, enable the interpreter to classify land masses according to their spectral reflectivity independent of intensity variation in the incident illumination. This capability, when viewed in conjunction with a high resolution image such as that produced by direct projection, should present the interpreter with the greatest amount of data available by additive techniques applied to ERTS MSS imagery.

Geologically, the advantage of the isoluminous imagery is its ability to enhance the relief and topography of the area. The drainage lines and patterns are clearly seen in the ranges with their deep valleys. In the basins, the drainage pattern stands out due to its negative topographic expression and the high contrast between the vegetation and background. Topographic volcanic features (plugs, cones, and necks) in the West Potrillo Mountains are very easily seen with their relief very discernable on the isoluminous imagery.

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