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STRUCTURE OF THE MIDCONTINENT BASEMENT -  
TOPOGRAPHY, GRAVITY, SEISMIC, AND REMOTE SENSING DATA

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## ABSTRACT

Some 600,000 discrete estimates of the Bouguer gravity of the continental United States have been spatially filtered to produce a continuous tone image. The filtered data were also digitally painted in color-coded form onto a shaded relief map. The resultant image is a colored shaded relief map where the hue and saturation of a given image element is controlled by the value of the Bouguer anomaly. Major structural features (e.g. midcontinent gravity high) are readily discernible in these data, as are a number of subtle and previously unrecognized features. A linear gravity low that is approximately 120 to 150 km wide extends from southeastern Nebraska, at a break in the midcontinent gravity high, through the Ozark Plateau, and across the Mississippi embayment. The low is also aligned with the Lewis and Clark lineament (Montana to Washington), forming a linear feature of approximately 2800 km in length. In southeastern Missouri the gravity low has an amplitude of 30 milligals, a value that is too high to be explained by simple valley fill by sedimentary rocks. Rather, the feature must be a basement structure. In fact, faults, fold axes, dikes and basement topography in Missouri trend in directions that are approximately parallel to the gravity low. Also, the New Madrid seismic activity is concentrated at the intersection of the gravity low with another linear low defining the Reelfoot rift within the Mississippi embayment. The seismic data indicate preferential movement along directions parallel to these two major trends. The origin of the linear gravity feature is problematical - it may be a rift, a

transcurrent fault, or some combination.

## INTRODUCTION

Understanding the basement structure of the midcontinental United States has obvious relevance to, for example, (a) Studies of the formation of continents, (b) Continental rifting, (c) The structure and economic geology of the overlying sedimentary cover, and in general, (d) The mechanisms by which continents respond to intraplate stresses. As part of a larger project with a goal of understanding the pattern, age, and origin of structures found within the Ozark Plateau and the St. Francois Mountains, we have examined digital gravity and topography data for the conterminous United States. In addition, we have examined seismic and selected remote sensing data for the Ozark Plateau and Mississippi embayment. The objectives of this paper are: (a) To describe a simple, but powerful technique of merging topographic and gravity data for map displays, (b) To illustrate the technique as applied to correlations between topography and gravity for the continental United States, and (c) To discuss a previously unrecognized basement structure that extends at least from the midcontinent gravity high, through the Ozark Plateau, and across the Mississippi embayment. The intersection of this feature and a northeasterly trending linear feature within the Mississippi embayment seems to control the location of seismicity within the New Madrid fault area.

## DATA PROCESSING METHODS

Approximately 600,000 gravity station readings for the continental U.S. were obtained courtesy of the Defense Mapping Aerospace Agency. Each reading has been corrected to a Bouguer anomaly through use of an assumed slab density of 2.67 gm/cm<sup>3</sup>. The average spacing between the station readings is about 4 km, although considerable variations occur in terms of station spacings. The value of the Bouguer anomaly for each station was scaled and quantized to an integer ranging in value from 1 to 255. The location of the station was then used to place the coded Bouguer value within a latitude and longitude grid, with a grid spacing of 1/120 of a degree. When this product is displayed as a gray-tone image it shows the locations of station readings, with bright grays corresponding to high anomalies and dark grays to lower anomalies (Figure 1). To facilitate visual interpretation and quantitative modeling of these data it is necessary to interpolate between data points. Contour maps, either done by hand, or by various machine methods, provide one means of interpolation. However, we chose another method, using a spatial filter to provide a continuous tone image from the discrete points (Eliason and Soderblom, 1977). The filter at any given position on the data array occupies a box of  $N \times N$  elements. The mean of the valid gravity data within the box is then used to create an interpolated value for the box center, if a valid data point does not exist for that location. Shifting the filter over the scene and repeating the operation results in a partially interpolated data set. Blank areas appear in zones

without any valid data or in zones that had so few valid points that a user-defined statistical threshold was not met. In practice, several filter passes were done, beginning with a 3 x 3 element filter, and ending with a 21 x 21 filter. Thus, in our gravity maps, features with wavelengths smaller than approximately 20 km have been removed by the filtering process. In addition, features with wavelengths close to the filter size appear with greatly reduced amplitudes.

The digital topographic data were obtained from NOAA and consist of estimates of the average elevation for an area that is 1/120 of a degree in latitude and in longitude. These data were formatted into an array with the same spacing as the gravity data. The problem then became one of merging the two data sets for an effective display of the correlations between gravity and topography. We chose to display topography in a shaded relief form, where the brightness of a given element within the map (called a picture element or pixel) is dependent on the local topographic slope, together with an assumed azimuth and elevation of the sun (Batson et al., 1977). Regional variations in brightness, based on the magnitude of gravity anomalies, can then be combined with the shaded relief map in a simple but effective way of merging topography and gravity. The technique involves digitally multiplying, pixel by pixel, the brightness of the shaded relief map with the brightness from the Bouguer anomaly map. The resulting image is a shaded relief map, where the brightness is modulated by both the local topographic slope and by the strength of the gravity anomaly.

The strength of the gravity anomalies can be also "painted" onto the shaded relief map in the following manner. The anomalies can be scaled to a color range, such as a range of colors that cover equal spectral intervals from blue through red wavelengths. Each pixel for the color-coded anomaly image can then be resolved into blue, green, and red components, since any hue, saturation and brightness can be produced by mixing these three primaries. Data for each pixel can then be plotted as a vector in blue, green, and red brightness space (Figure 2). The hue and saturation associated with each pixel is defined on the basis of the direction cosines associated with the vector, while the brightness is proportional to the vector length. A color "painted" relief map can be constructed by digitally replacing the vector length with a length based on the brightness from the shaded relief map for a given pixel. New blue, green, and red components can then be computed and combined to produce a color-coded anomaly map, with the brightness modulated by the shaded relief map, and the hue and saturation controlled by the Bouguer anomaly data.

#### BOUGUER GRAVITY COLORED RELIEF MAP OF CONTINENTAL UNITED STATES

Figure 3 shows a color map constructed by letting the shaded relief data control the brightness, while the hue and saturation are controlled by the Bouguer data. The color coding scheme was chosen so as to equally discriminate changes in the Bouguer anomalies throughout the anomaly range. A number of major, previously recognized features can be delineated, along with a number of



subtle, previously unrecognized features. The major features are shown in a sketch map in Figure 4. In this paper we concentrate on structures located within the midcontinent. The midcontinent gravity high can clearly be seen. This feature is about 70 km wide, contains 1.1 billion year old basalts, and has been interpreted as a failed continent rift (Chase and Gilmer, 1973). Considerable structure can also be seen in the greenstone-granitic terrain located to the northwest of the midcontinent gravity high. The Wisconsin Arch, the Mississippi embayment, the Ouachitas, and the Wichita-Arbuckle system can also be discerned.

A number of more subtle features can be seen in the midcontinent by examining the color map in Figure 3 and a gray-tone map of Bouguer anomalies that has been specially enhanced for the midcontinent (Figure 5). For example, there is a linear gravity low that begins at the left lateral offset in the midcontinent gravity high in southeastern Nebraska, cuts through Missouri in a NW-SE direction, passes through the Mississippi embayment and possibly abuts against the Appalachian valley and ridge province in Alabama. This feature, which we will call the Missouri gravity low, is aligned with a valley of the Platte River and with the Lewis and Clark lineament (Montana to Washington). The feature is also aligned with the extensive Mesozoic dike swarms located in the piedmont province of South Carolina. Thus, based on gravity, topography, and geology, the Missouri gravity low appears to be part of a major basement structure. Note that the feature bends toward the south in middle Missouri, perhaps at a junction with a subtle feature that strikes in a northeasterly direction toward Lake

Michigan. Other features, such as a linear gravity high extending from Lake Michigan southeasterly to the Appalachians can also be discerned (Figures 3,4), but will not be discussed further here.

#### PROFILES ACROSS THE MISSOURI GRAVITY LOW

Figure 5 is a gray-tone form of the Bouguer image for a region covering the Missouri gravity low and surrounding regions. The low extends to the Mississippi Embayment where it connects with the previously recognized low known as the Pascola Arch (Ervin and McGinnis, 1975). Two profiles, A-A' and B-B' were used to model the Missouri low in terms of the thickness of sedimentary fill that would be needed to explain the anomaly. The model accepts residual anomalies (i.e. with the regional field removed) and then computes the thickness of a uniformly-spaced set of prisms needed to best match the observations. The prisms are assumed to be infinite in extent perpendicular to the profile. Independent variables that can be changed to minimize residuals between the data and the model fit are the thickness of each prism and the density contrast between the prism and the basement rock (Cordell and Henderson, 1968). Good fits to the data can be obtained if the density contrast is set to 0.2 gm/cm<sup>3</sup> (Figure 6). The predicted sedimentary column thickness would then be 4 km at AA' and 2 km at BB'. However, Kisvarsanyi (1975) reports that the sedimentary column thickness is only a few hundred meters in these areas. Also, since typical density contrasts between sedimentary and basement rocks are probably less than 0.1 gm/cm<sup>3</sup>, even greater sedimentary column thicknesses would

be needed to fit the data. Thus, we conclude that the gravity low cannot be due to a thick sedimentary fill. Rather, it must be due to a basement structure. Cordell (1979) reached a similar conclusion based on analysis of the northern edge of the low in the 1" x 2" Rolla quadrangle. Assuming a density contrast of 0.5 gm/cm<sup>3</sup> between crust and mantle, a crustal thickening of about 1.5 km would be consistent with the 30 mgal anomaly observed at AA'.

#### SEISMIC DATA IN THE VICINITY OF THE MISSOURI GRAVITY LOW

The location of the gravity low and, in particular, its intersection with the Mississippi embayment (the Reelfoot Rift), seems to have controlled the location of the New Madrid seismic zone. Figure 7 is a plot of Earthquake epicenters as determined by the St. Louis University seismic network (Stauder et al., 1977), overlaid onto a gray-tone form of the Bouguer anomaly image. There are clearly two dominant trends, one striking in a northeasterly direction and the other in a northwesterly direction. The northeasterly trend presumably delineates the presently active section of faults within the Reelfoot rift (Hildenbrand et al., 1977). An offset in the linear pattern exists in the northwesterly trend, forming two trends that are parallel to the northeastern edge of the Missouri gravity low. Thus, the intersection of the gravity low with the Mississippi embayment seems to be a fundamental aspect of the New Madrid seismic zone. Perhaps the intersection of the two features forms a zone of weakness that is susceptible to brittle failure due to intraplate stresses.

## THE MISSOURI GRAVITY LOW AND REMOTE SENSING DATA

The Missouri gravity low is clearly a basement feature. Kisvarsanyi (1974) notes that dike swarms in Missouri strike dominantly in a NW direction. Also, the Central Missouri basement topographic high is located on the southwestern edge of the gravity low and strikes in the same direction as the low. As shown in McCracken (1971), most of the surface structures in Missouri are high angle normal faults that strike in a northwesterly direction. The correlation between the strike of the gravity low and structural features can be illustrated through use of remote sensing data covering the Ozark Plateau. The Ozark Plateau was apparently a peneplain at the beginning of the Tertiary period, based on the presence of gravel deposits capping some of the higher hills in the region (Bretz, 1965). However, an apparent uplift of the region caused the streams in the area to cut down to depths of 30 to 40 meters. The resulting relief patterns, to the extent that the channels are fault-controlled, provide a means to map basement structures that have propagated through the Paleozoic sedimentary section that overlies most of the region.

We have utilized Heat Capacity Mapping Mission (HCMM) data, together with the NOAA digital topography data, to synthesize an image that portrays topographic variations. HCMM consisted of a satellite with a capability to image the surface in the visible (0.3 to 2.5 microns) and in the thermal infrared (10.5 to 12.5 microns) part of the spectrum (Price, 1977). An apparent thermal inertia image can be constructed from HCMM data by use of the following

formulation:

$$T.I. = (K(1-A))/(DAY-NIGHT)$$

Where T.I. is the apparent thermal inertia of the surface, K is an arbitrary scaling constant, A is the albedo, DAY is the brightness of a given pixel in the daytime IR image, and NIGHT is the brightness for the same area in the nighttime image. The resultant image is termed an apparent thermal inertia image because: (a) The effects of atmospheric emission have not been eliminated and (b) The effects of topography on differential heating of the surface have not been eliminated. The thermal inertia is a measure of the thermal response of the surface to temperature changes. For Missouri, the response is a complicated function of the soil and rock exposures, together with variations in vegetative cover.

Figure 8 is an image that was produced by multiplying, on a pixel by pixel basis, the apparent thermal inertia from HCMM data, with the shaded relief map. The image is, in effect, a shaded relief map where the regional trends are modulated by the apparent thermal inertia of the surface. Since our simple formulation did not remove topographic effects and since the resultant apparent thermal image would have gray tone variations related to topography, the net effect of such a data merging is to enhance very subtle topographic variations. Clearly, the northwesterly trend of the topography of Missouri can be discerned on this image. Some of these topographic linears correspond to mapped faults. Others do not and we are currently pursuing field studies aimed at identifying

the origin of some of these linear features.

#### POSSIBLE ORIGINS OF THE MISSOURI GRAVITY LOW

The origin and detailed basement characteristics of the Missouri gravity low are difficult to determine at this stage. The feature changes with increasing distance from the mid-continent gravity high. Close to the mid-continent gravity high the feature can be viewed as a broad trough with a medial high (BB' in Figure 5) while farther away the feature becomes a broad low (AA' in Figure 6). The axial high has about the same Bouguer values as the surrounding regions, in contrast to the midcontinent gravity high. As discussed, the Missouri gravity low connects with the Pascola Arch to cut across the Mississippi Embayment. Also, the gravity low lies along the southeastern projection of the Lewis and Clark Lineament, forming a combined gravity-topography signature that may extend for about 2800 km in length. Perhaps the most plausible explanation is that the gravity low may be as part of an extensive transcurrent fault system or a failed continental rift. Most likely, parts of the system were reactivated during various periods, perhaps explaining why the system has no obvious expression just to the northwest of the midcontinent gravity high.

#### ACKNOWLEDGMENT

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## FIGURE CAPTIONS

- Figure 1 - Plot showing gravity data points for region centered over Illinois and Missouri. Latitude, longitude boundaries for the map correspond to 33 to 45° N., and 86 to 98° W., respectively.
- Figure 2 - View of red, blue, green (e.g. Primary) color space showing how the relationships between the three primaries and hue, saturation, and brightness. The brightness of a color image can be modulated by the brightness of another image by replacing the original vector length with a length based on the brightness of the other image.
- Figure 3 - Mercator projection of the continental United States showing the topography in shaded relief form, and the Bouguer anomalies as a set of overlaid colors. The simulated sun is from the west at 15° above the horizon. The approximate color-coding scheme for the gravity data is as follows: red, less than -200 mgals; yellow, -200 to -65 mgals; green, -65 to -35 mgals; light blue-green, -35 to 0 mgal; and dark blue, greater than 0 mgal. Black areas correspond to zones of bad gravity data or to regions of little or no data.
- Figure 4 - Sketch map showing major structural features evident from Figure 3.

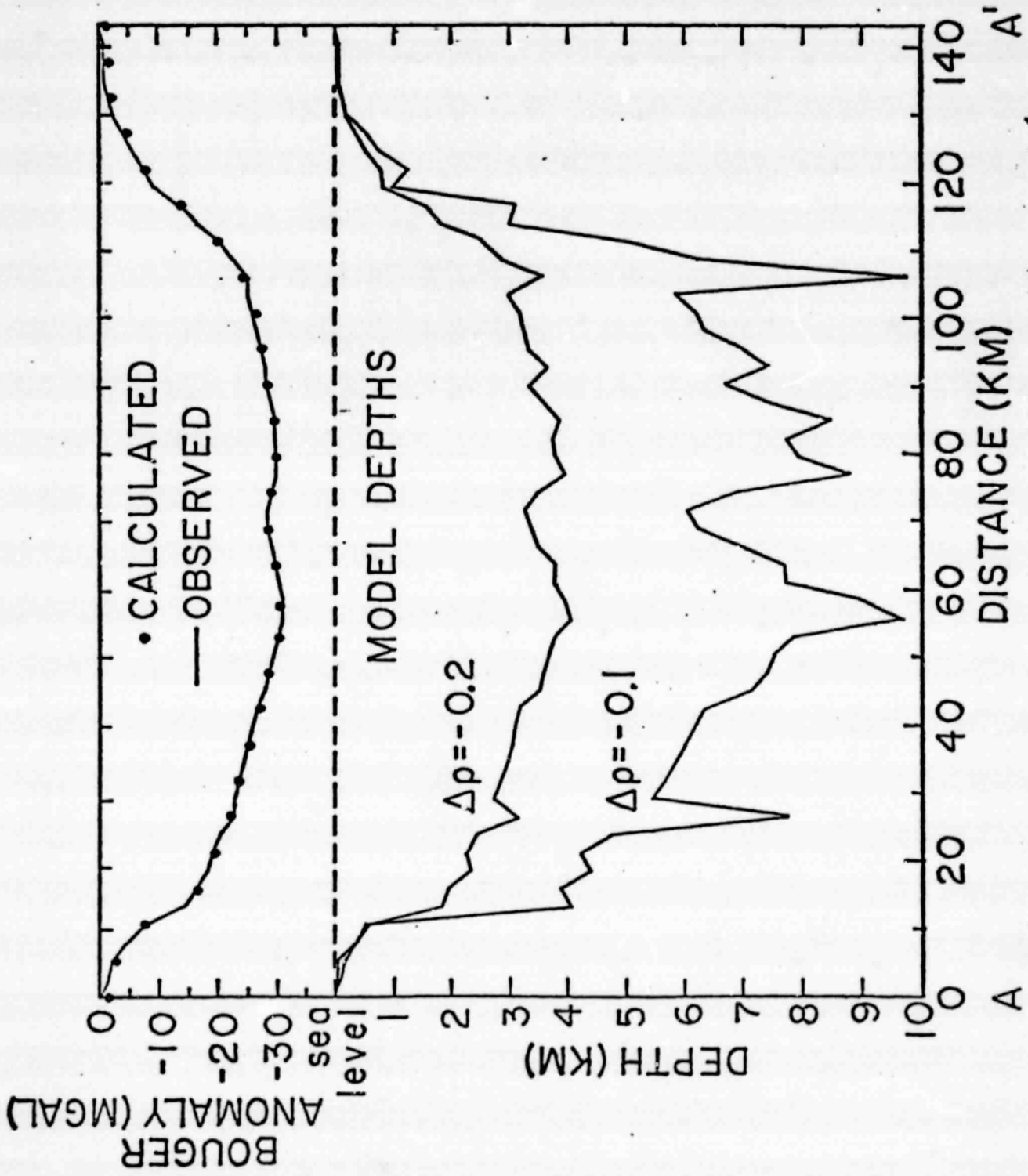
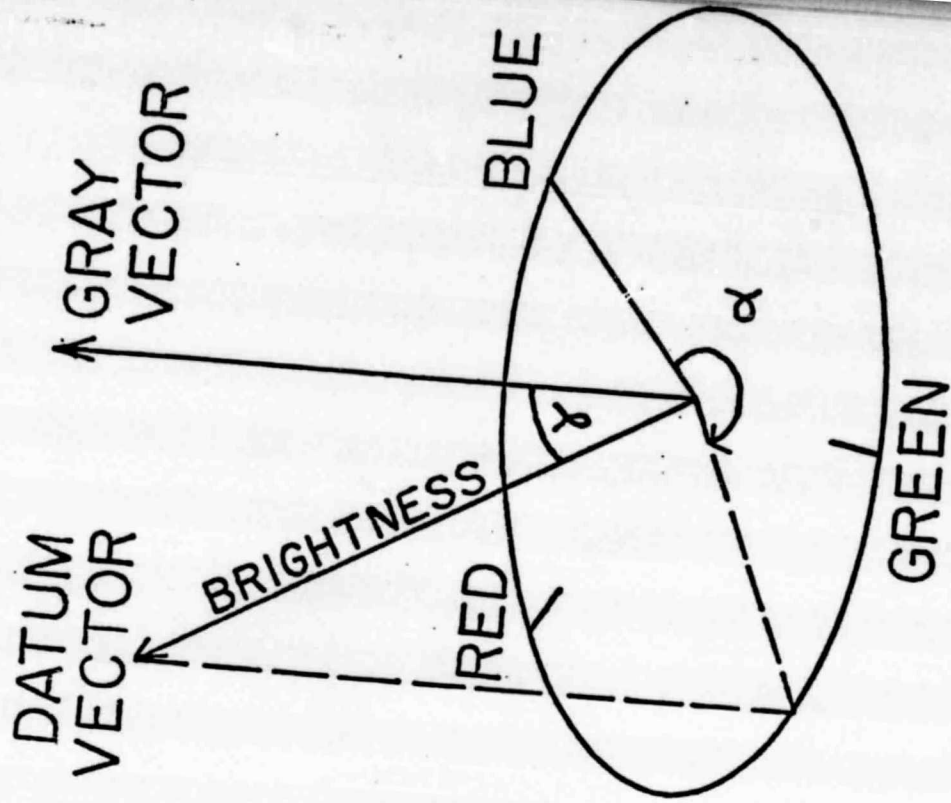
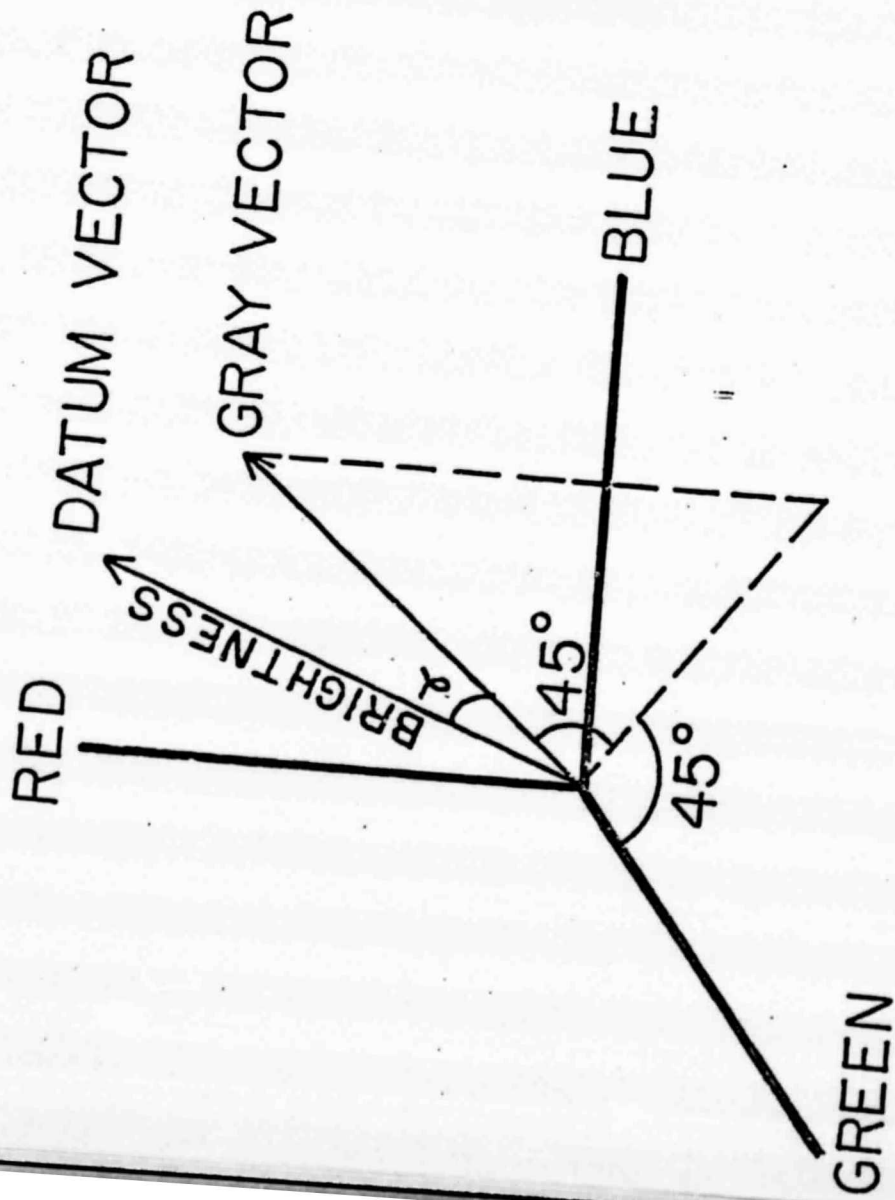


FIGURE 6

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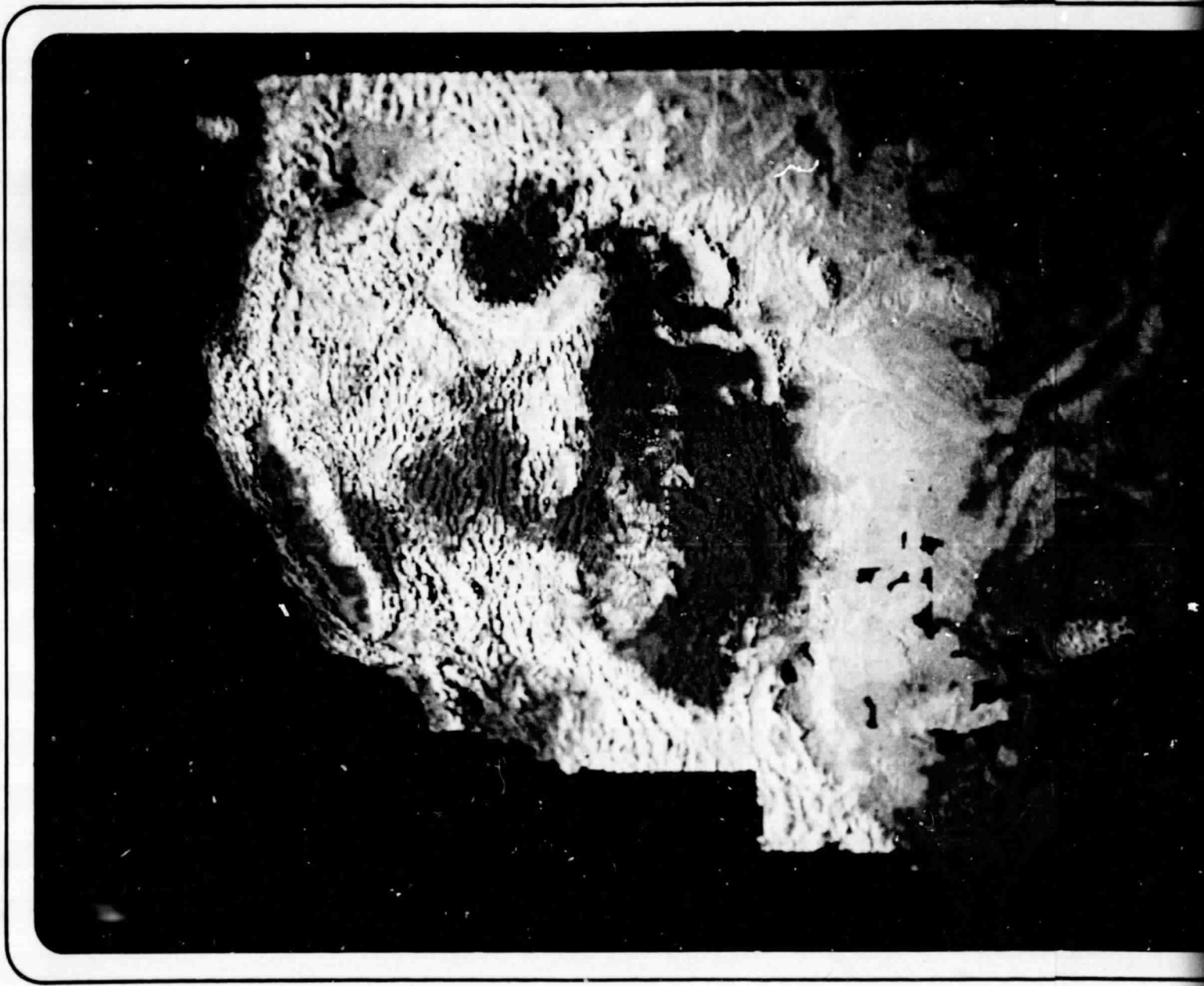


FIGURE 1



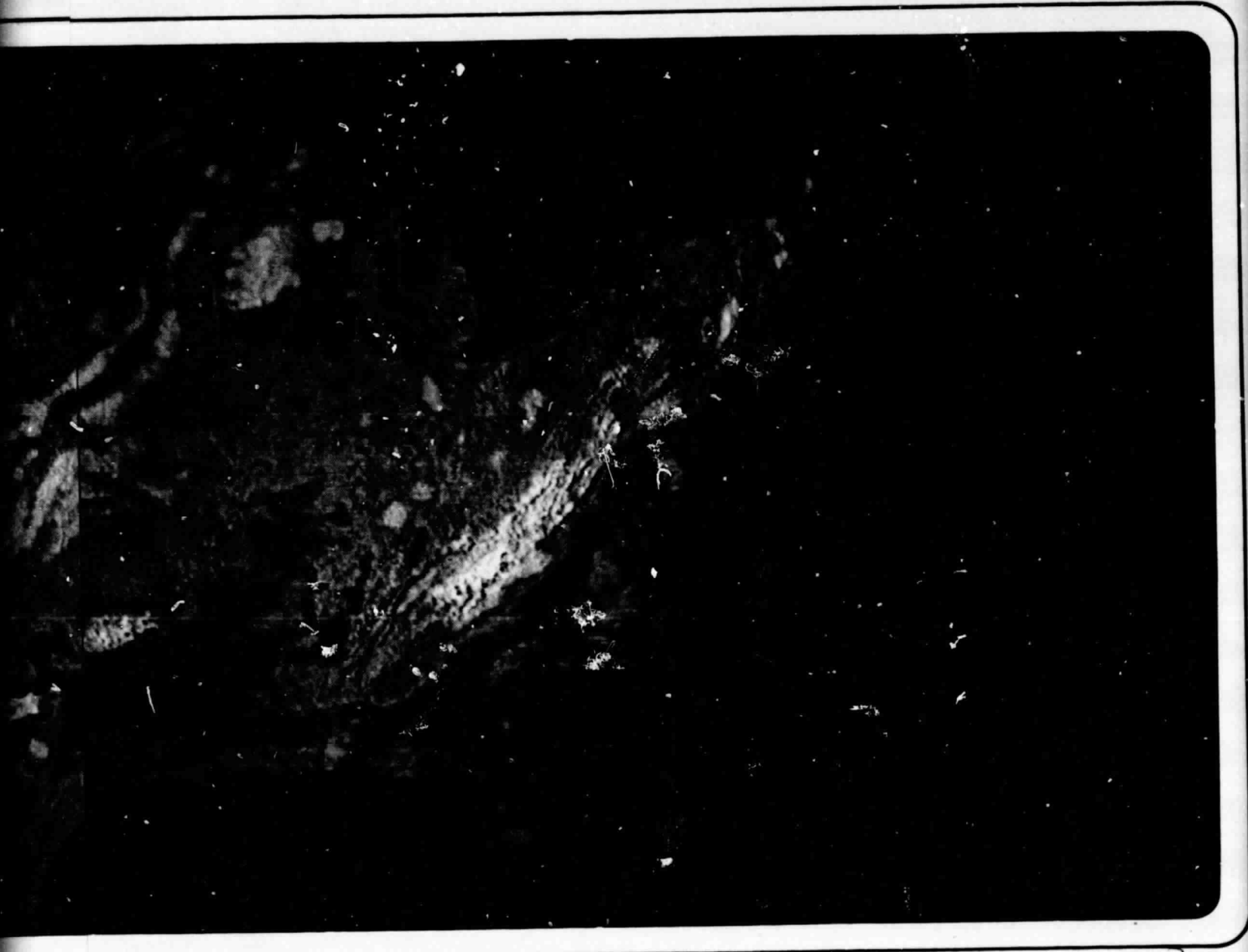
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FIGURE 2



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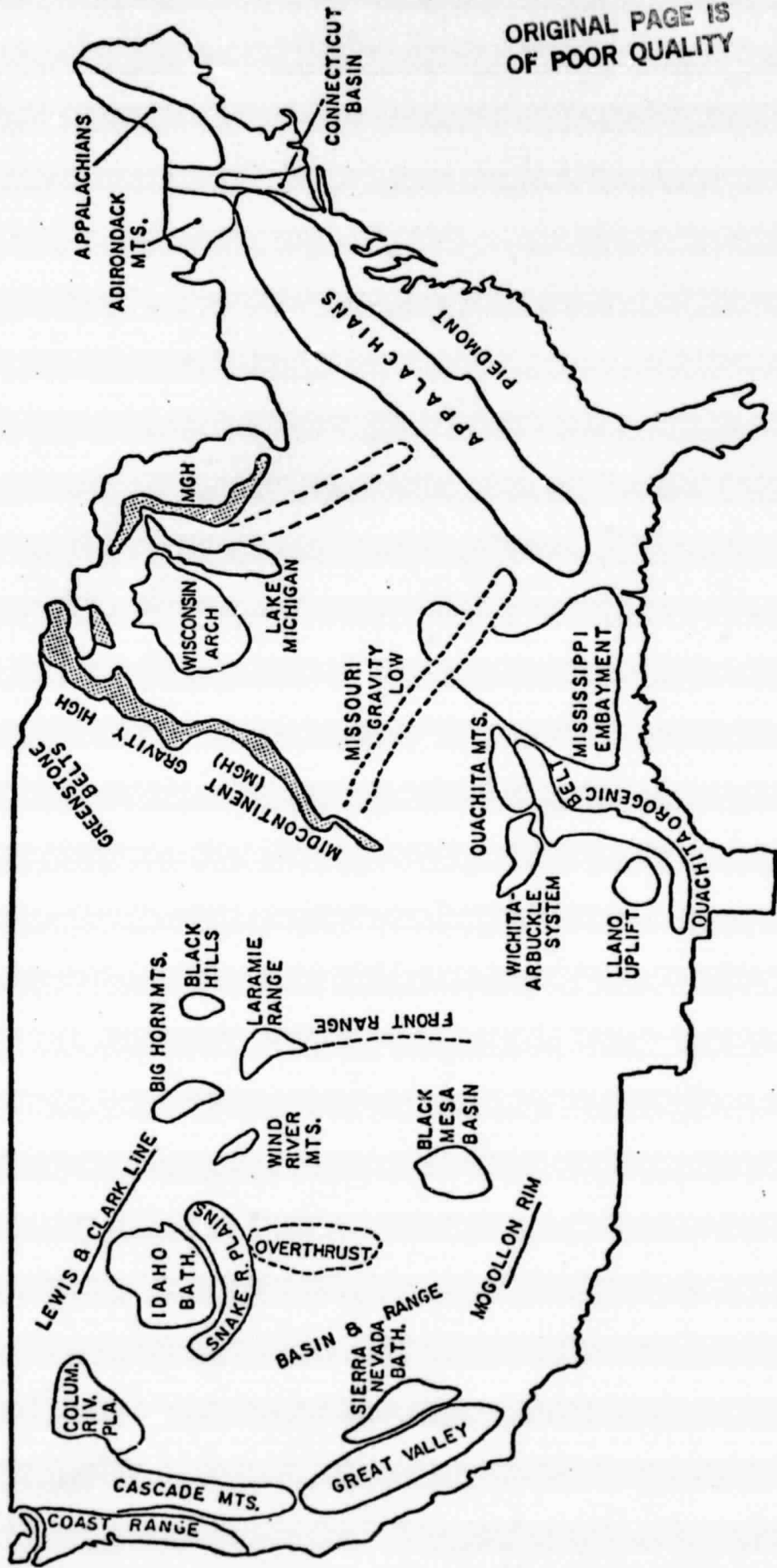


FIGURE 4



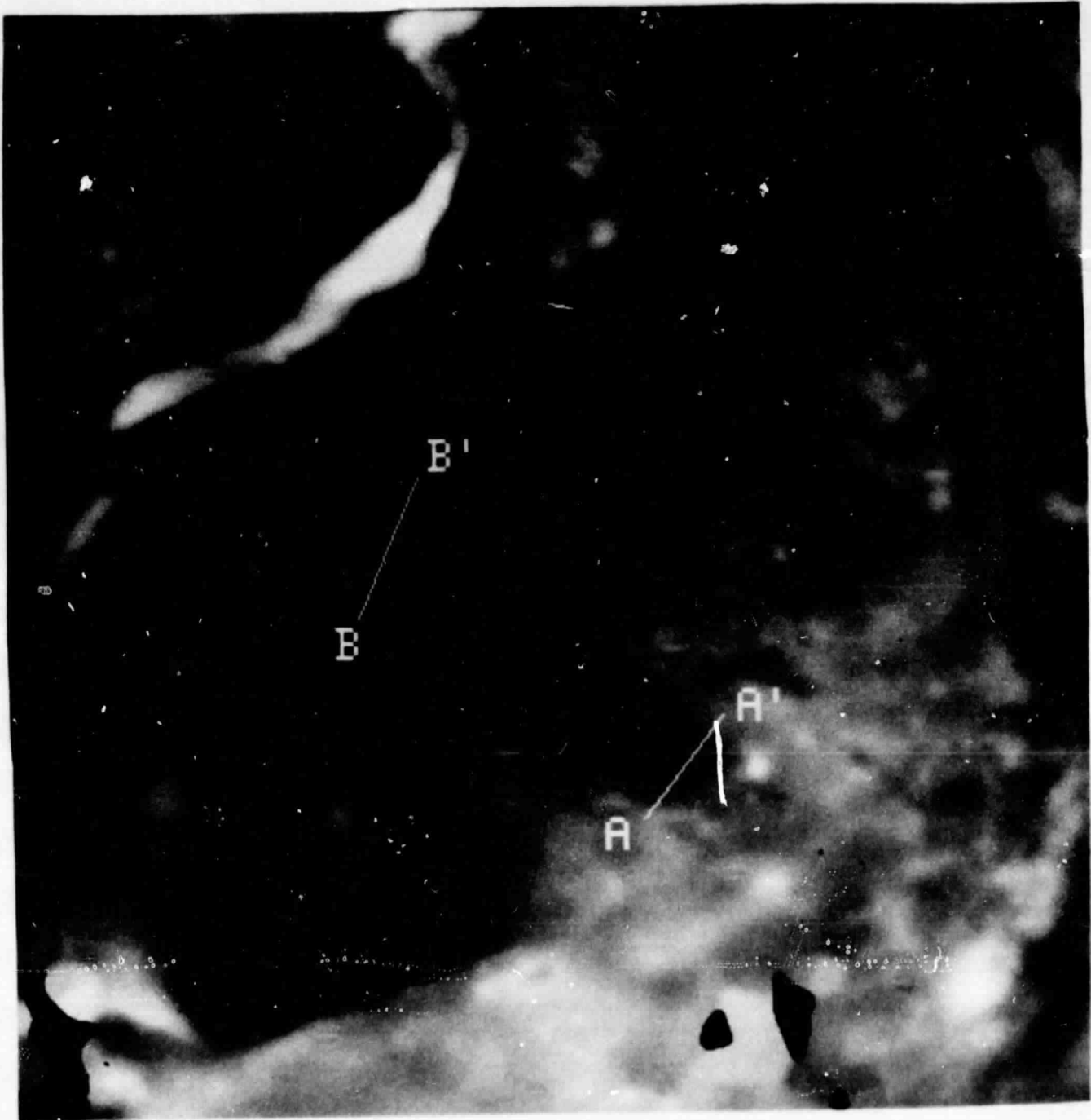


FIGURE 5

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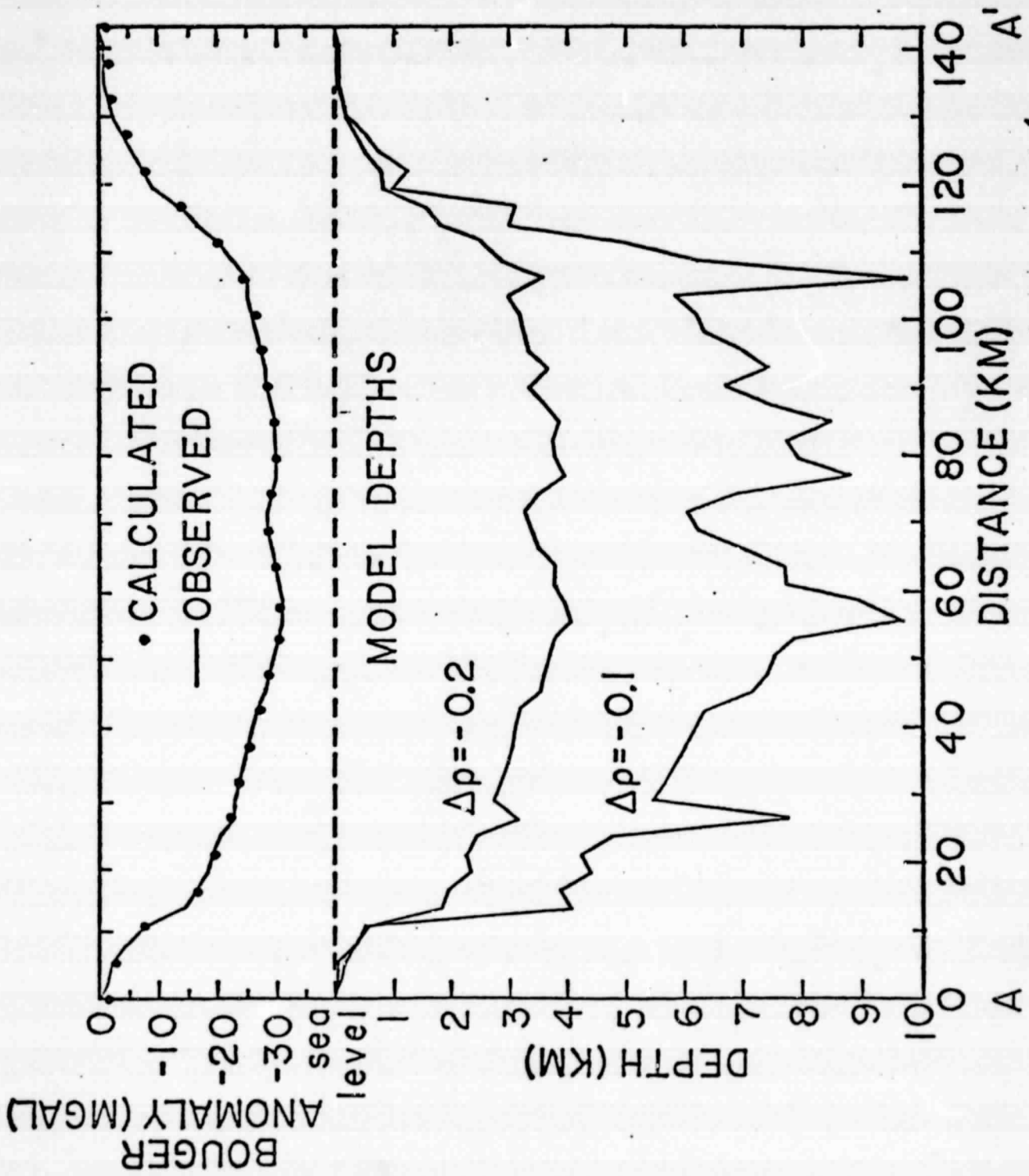
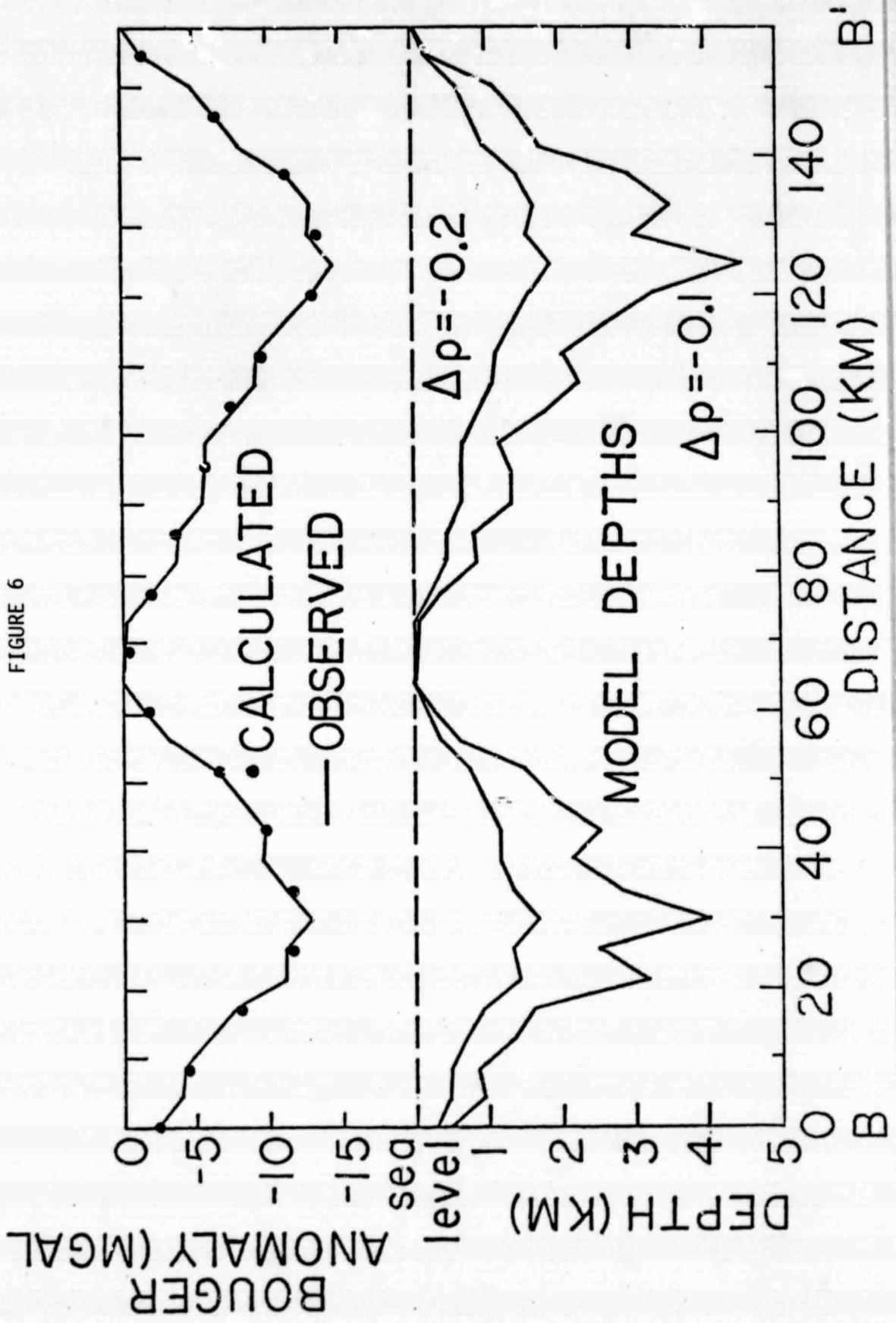
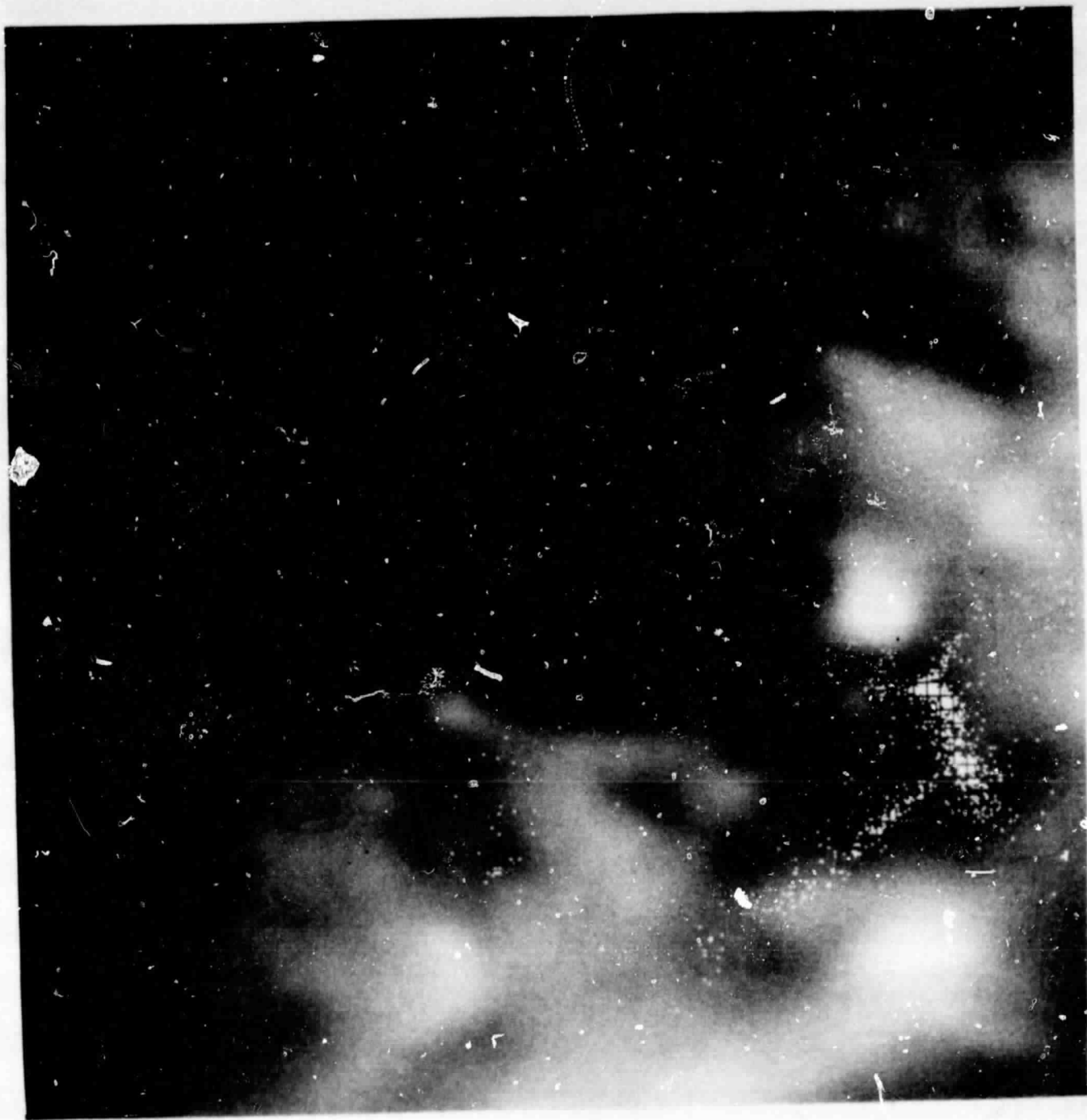


FIGURE 6

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FIGURE 7

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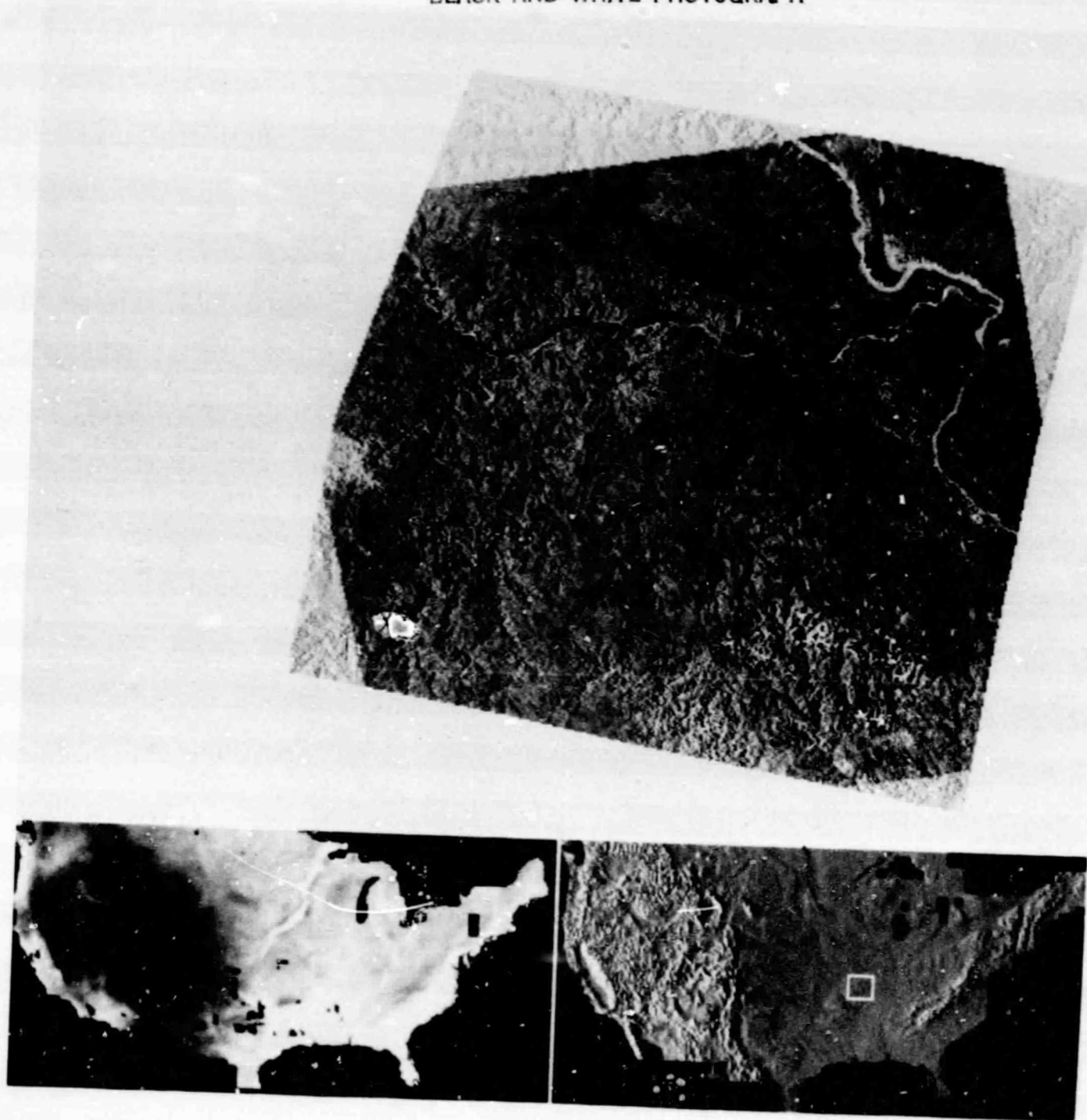


FIGURE 8