Geological Mapping Potential of Computer-Enhanced Images from the Shuttle Imaging Radar: Lisbon Valley Anticline, Utah

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ABSTRACT: Computer-enhancement techniques applied to the SIR-A data from the Lisbon Valley area in the northern portion of the Paradox basin increased the value of the imagery in the development of geologically useful maps. The enhancement techniques include filtering to remove image speckle from the SIR-A data and combining these data with Landsat multispectral scanner data. A method well-suited for the combination of the data sets utilized a three-dimensional domain defined by intensity-hue-saturation (IHS) coordinates. Such a system allows the Landsat data to modulate image intensity, while the SIR-A data control image hue and saturation. Whereas the addition of Landsat data to the SIR-A image by means of a pixel-by-pixel ratio accentuated textural variations within the image, the addition of color to the combined images enabled isolation of areas in which gray-tone contrast was minimal. This isolation resulted in a more precise definition of stratigraphic units.

INTRODUCTION

FOR MORE THAN A DECADE, images of the Earth's surface taken from space have provided geologists with a useful tool for geologic exploration. One of the more recent data products is L-band radar imagery acquired by the Shuttle Imaging Radar (SIR-A) which was launched in November, 1981, aboard the space shuttle Columbia on its second flight. Unlike previous satellite imaging systems, the SIR-A system was intended specifically for geologic use.

The purpose of this study was to determine whether or not computer enhancement of SIR-A imagery increased the potential for extraction of geologic information from the images. The enhanced images are produced by digitally combining the SIR-A radar data with corresponding Landsat multispectral scanner (MSS) data. Data from the Landsat Thematic Mapper (TM) were not readily available when this study began. It is believed, however, that the higher resolution imagery generated by this sensor can be similarly combined with the radar imagery, and would likely produce comparable if not superior results.

The area selected for the evaluation of the SIR-A imagery lies along the Utah-Colorado boundary in the northern part of the Paradox Basin, a Pennsylvanian sedimentary basin within the Colorado Plateau province. This area was selected from the catalog of imagery generated during the test mission because of the variety of geologic features exposed at the surface and the need for developing an understanding of the differences in their radar responses. The area is dominated by Lisbon Valley salt anticline, with widespread surface exposure of rocks of various lithologies and ages, and abundant regionally extensive faults.

To evaluate the mapping potential of the SIR-A imagery, the suspected geologic units, as mapped on each image or image combination, were compared to the units delineated on published maps and verified in the field. From these comparisons any improvements resulting from the different enhancement techniques could also be evaluated. Therefore, this study not only indicates the type and amount of geologic information that can be observed in this environment on imagery, but also presents some approaches for increasing the amount of information revealed.

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IMAGE ENHANCEMENT

METHODS

Magnetic tapes of the SIR-A and Landsat scenes covering the study area were acquired for computer-enhancement and interpretation. The digital SIR-A data had been converted from the optically recorded data film segment using an Optronics C-4500 scanner. The Landsat data included portions of two adjoining scenes (038-033 and 038-034) recorded on the same day (12 June 1977). The final images used in the interpretation were subscenes limited to 512 by 512 pixels, the maximum dimensions of the display system used for this study. Based on previous studies for revelation of geologic data (for example, Anderson and Smith, 1975; Prelat and Lyon, 1978; Fernandez *et al.*, 1978) and visual comparisons, only Landsat bands 5 and 7 imagery were selected for further processing and merging with the radar data.

The information content of the enhanced satellite images was evaluated through comparison of photographic prints of the image combinations at a scale of 1:250,000 with published geologic, topographic, and vegetation maps. A field reconnaissance of the study area was conducted to obtain information about surface characteristics which determine the strength of radar backscatter such as a slope, microrelief, vegetation, and weathering effects. Each image type was evaluated for the degree of discrimination between adjacent photolithologic units at the formation level (Table 1).

MEDIAN FILTER

One problem that results from using coherent electromagnetic energy, such as radar, to illuminate a surface is speckle. In this study speckle was reduced using a median value filter. The filter operated with a window size of 5 by 5 pixels. The filtered image (Plate 1, lower) when magnified and displayed using the processing system, is not only more pleasing to the eye, but resulted in improved accuracy in selecting control points for the SIR-A/Landsat scene registration.

CONTRAST STRETCH AND COREGISTRATION

To improve the quality of the satellite images, contrast stretching was applied to re-scale the individual pixels' gray level values to make use of the entire available dynamic range (Lillesand and Kiefer, 1979). Subsequently, in order to combine the Landsat data with the SIR-A data, it was necessary to coregister the data sets. The warping technique employed used the location of 15 to 20 identical points manually selected from corresponding images, to compute the coefficients of a least-squares fit polynomial (Billingsley, 1983). These coefficients were then used for rotating and distorting the Landsat image (Plate 2) into spatial register with the reference image (SIR-A) (Blom and Daily, 1982; Daily *et al.*, 1978; and Stewart *et al.*, 1980).

RATIOS

Ratio images of the Landsat scene were produced by dividing the brightness values from each pixel of band 5 by those of band 7. Additional ratio images were then produced by dividing SIR-A brightness values by those of band 5, band 7, and bands 5/7. Each of these combinations required post-ratio contrast stretching. The SIR-A/Landsat ratio provides a means for displaying the information from both sensors simultaneously without the use of color. Accordingly, Landsat compositional information sometimes enhances subtle features within an area of uniform brightness on the SIR-A images (Rebillard and Evans, 1983).

IHS MERGE

Many previous geological studies utilizing the combination of two or more images of different wavelengths have shown different degrees of success (Rowan *et al.*, 1974; Daily *et al.*, 1978; Stewart *et al.*, 1980; Blom and Daily, 1982; Elachi, 1982; Elachi and Granger, 1982; Elachi *et al.*, 1982; Zall *et al.*, 1982). Color SIR-A/Landsat images were produced for this study by utilizing a three-dimensional domain defined by an intensity-hue-saturation (IHS) coordinate system (Buchanan and Pendergrass, 1980). In a qualitative sense, for any pixel in the scene, intensity constitutes the average brightness, hue differentiates color, and saturation describes the vividness of hue (Daily *et al.*, 1978). This relationship allows the factors that contribute to a pixel's appearance to be divided between the two types of data. Here, SIR-A brightness values were selected to control hue and saturation, while the Landsat values controlled intensity. The three component values (IHS) were then normalized to levels greater than or equal to the range of visual perception; i.e., 2^8 levels of intensity, 2^5 levels of hue, and 2^3 levels of saturation (Buchanan and Pendergrass, 1980).

By selecting the radar data to control hue and saturation rather than intensity, the objective of evaluating the discriminating capabilities of SIR-A could be more accurately determined. It was believed that changes in color due to differences in radar return would be easier to identify and map than changes in brightness. In the resulting image, pixels in areas of high radar return are shown as highly saturated yellow or green. On the other hand, areas of low return are shown as blue or purple and have low saturation values. The intensity values, in either case, are controlled by the Landsat brightness values and, therefore, can vary independently of the hue-saturation values.

THE LISBON VALLEY AREA

GEOLOGY

The salt anticline region of southeastern Utah and southwestern Colorado is situated in the northern

Unit	Adjacent Units	Filtered		Ratio		Color	
		Contact*	Gray Tone	Contact	Gray Tone	Contact	Color
Qae			Black		Black		Blue-White
	Q1	NV		NV		NV	
	Kd	· / NV		· / NV		• / NV	
	Kbc	●		●		●	
	Jmse	●		●		●	
	Trn	● / ·		● / ·		● / •	
	Trkw	●		●		●	
	Trc	•		•		●	
	Pc	•		•		●	
	Phu	●		●		●	
	Phl	•		●		●	
Q1			Lt. Gray		Lt. Gray		Pink and Green
	Kbc	NV		·		•	
	Jmse	NV		NV		NV	
Kd			Dk. Gray		Dk. Gray		Purple-Blue
	Kbc	●		●		●	
Kbc			White		White		Green
	Jmse	·		·		•	
Jmse			Lt. Gray		Gray		Pink and Green
	Trn	·		·		·	
	Trkw	·		·		•	
Trn			Gray		Dk. Gray		Pink
	Trkw	·		•		●	
Trkw			White		Lt. Gray		Yellow-Green
	Trc	·		•		•	
Trc			Black		Lt. Gray		Orange
	Pc	·		•		•	
Pc			Dk. Gray-Lt. Gray		Gray-Lt. Gray		Pink or Yellow
	Phu	● / ●		● / •		● / ●	
Phu			Dk. Gray		Gray		Purple
	Phl	●		•		●	

*Two entries indicate differences in smooth/rugged topography.

Contact Visibility

NV - Not Visible
· - Poor
• - Moderate
● - Sharp

TABLE 1. Comparison of unit discrimination in the Lisbon Valley area using filtered, ratio, and color images.

and central portions of the Paradox sedimentary basin, a basin defined as that area underlain by salts of Middle Pennsylvanian age (the Paradox Member of the Hermosa Formation). The Lisbon Valley anticline is one of several parallel northwest trending Pennsylvanian age salt anticlines that are exposed in this portion of the Paradox basin (Figure 1).

The northeastern side of this anticline has been dropped approximately 1,200 m along the Lisbon Valley fault. This downthrown side of the anticline dips 6° into the East Coyote syncline (Huber, 1981). Rocks cropping out in the Lisbon Valley area range in age from Pennsylvanian (Hermosa Limestone) to Cretaceous (Dakota Sandstone).

VEGETATION

The vegetation of the salt anticline region is similar to that of other areas of the Colorado Plateau having semiarid climates. The dominant types are Juniper-Pinyon woodlands on rocky terrain, and Great Basin Sagebrush mostly in the valleys where the soils are deep. In addition, Saltbush-Greasewood and Galleta-Three awn Shrubsteppe are abundant in some of the flat-lying areas (Kuchler, 1964). In general, vegetation (other than short grasses) in this area is sparse, covering not more than approximately 20 percent of the surface. Typical cover can be seen in the ground photos in Plate 3. Plate 3 also illustrates the insignificant contribution of the vegetation to the radar return signal. The vegetation shown in Plate 3 (upper) was observed over alluvial and eolian deposits in an area of little or no signal return, while a similar cover shown in Plate 3 (lower) was observed over sandstone and siltstone outcrops in an area of moderate to strong return. This suggests that the recorded signal is dominated by contrasts in rock,

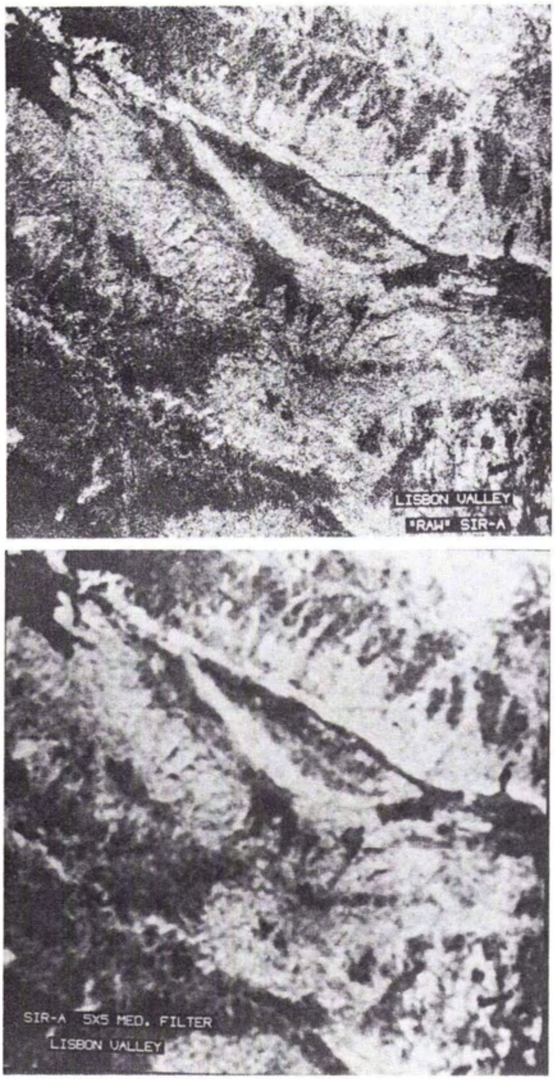

PLATE 1. Comparison of "raw" (upper) and filtered (lower) SIR-A images.

soil, or alluvial characteristics rather than changes in vegetative cover.

These observations may appear to contrast with some of those reported by Blom and Elachi (1981) in their study of the influence of sand dune vegetation on the radar return signal. However, they reported that, although vegetation strongly influences the higher resolution X-band radar return signal, it had little or no effect on the Seasat L-band signal. Inasmuch as the SIR-A system is a modification of the Seasat system, our observations appear to be consistent with this earlier study.

UNIT RECOGNITION AND DISCRIMINATION

The relative differences between image combinations in rock-type discrimination are

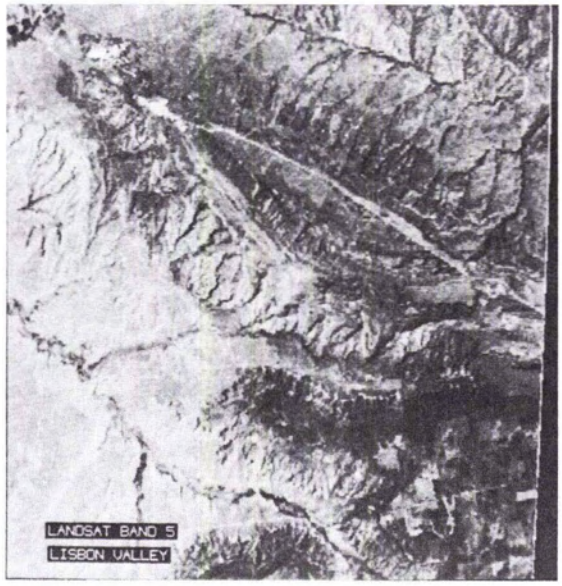

PLATE 2. Single band Landsat image of study area.

presented in Table 1. The results for the ratio (SIR-A/Landsat) and color (IHS controlled) images listed in this table represent a summation of the three Landsat band combinations used in the image construction (i.e., SIR-A combined with Landsat bands 5, 7, or 5/7). No geologically significant differences were found to have resulted from the selection of a particular Landsat band. Although differences between the signatures of any unit on the three combined images are visible, the capacity for discrimination of distinct geological units has not been altered. This is primarily a function of the sparsity of vegetation in this semi-arid region, an element normally of prime importance in producing contrast between the band 5 and band 7 images.

For the most part, the alluvial and eloian deposits (Qae) are easily distinguished from each of the other rock units on the images (Plates 4, 5, and 6). They are characterized by areas of little or no return (black) on the filtered SIR-A and SIR-A/Landsat ratio images. On the color-enhanced images they appear white or gray. This lack of signal return is a result of specular reflection from the flat, low microrelief surfaces largely covered by a mixture of grasses and sagebrush associated with the alluvial and eloian deposits (Figure 1). In contrast to these deposits, brighter tones from discordant, sinuous segments of the washes are visible. Using Rayleigh's criterion for roughness, the wash deposits should, and do, appear rough (brighter) if the microrelief (h) is

$$h > \frac{\lambda}{8 \sin \alpha}$$

in which λ is the operating wavelength and α is the

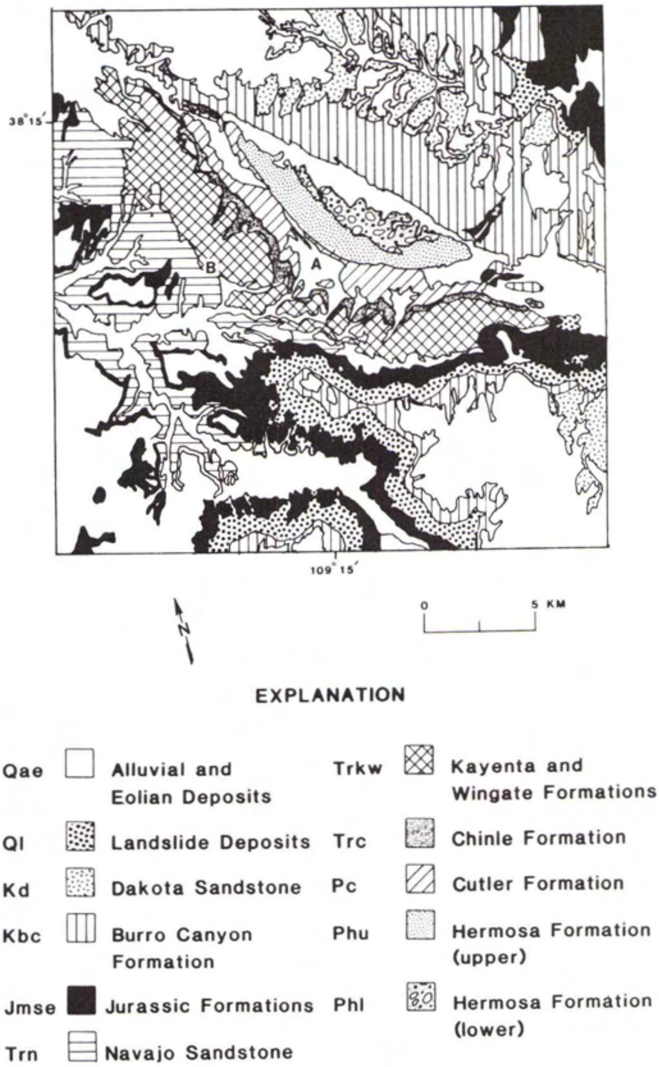

FIG. 1. Major geologic units of the Lisbon Valley area (after Williams, 1964).

depression angle. Additionally, if the wash deposits are aligned at right angles to the beam direction, bank slopes on the far range side of the wash would be imaged at a reduced local incidence angle, thus increasing the energy returned to the antenna.

The Burro Canyon Formation is characterized by a surface that appears rough to the L-band radar and, as a result, produces a strong signal return. Such a return would not be expected if surface slope dominated the signal's response inasmuch as the formation dips away from the radar beam. Thus, with this orientation the local incidence angle is increased and a weak, not a strong, signal should have been returned.

On the filtered SIR-A image, the upper Hermosa Formation is similar in tone to the Burro Canyon Formation and would likely be photo-mapped as the same unit. However, on the SIR-A/Landsat ratio images, the addition of Landsat MSS data increased the textural variations between these units, enabling their separation. On these images the upper Hermosa Formation appears smoother and darker than the Burro Canyon. Other improvements in the discrimination between adjacent units obtained with SIR-A/Landsat ratio images are shown in Table 1.

The ability to discriminate the lower unit from the upper unit of the Hermosa Formation is probably due to a combination of micro- and macrorelief. The slope face of much of the upper unit dips directly toward the transmission direction of the radar beam. In those areas the low local incidence angle provides for an increased signal return. This cannot be the only factor responsible for the units' differences, however, because a strong return signal is also

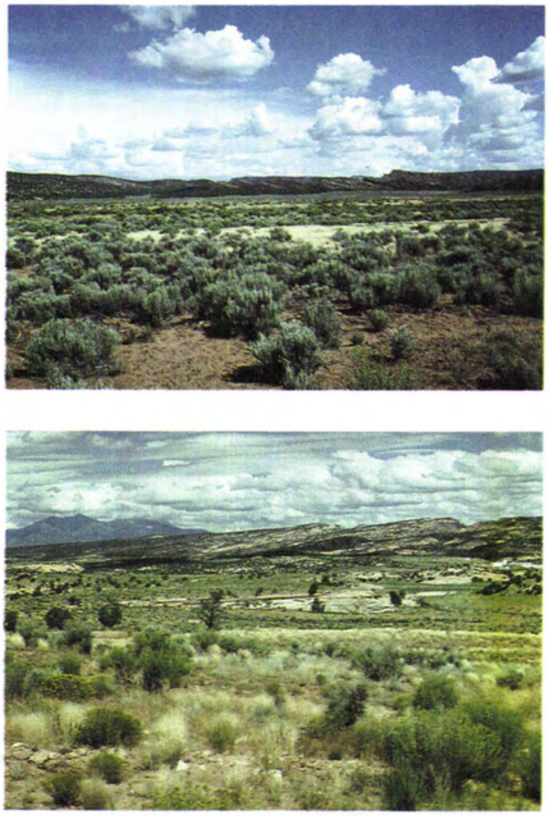

PLATE 3. Ground photos showing vegetation of the Lisbon Valley area. The locations shown in the upper and lower photos are indicated by letters A and B, respectively, in Figure 1.

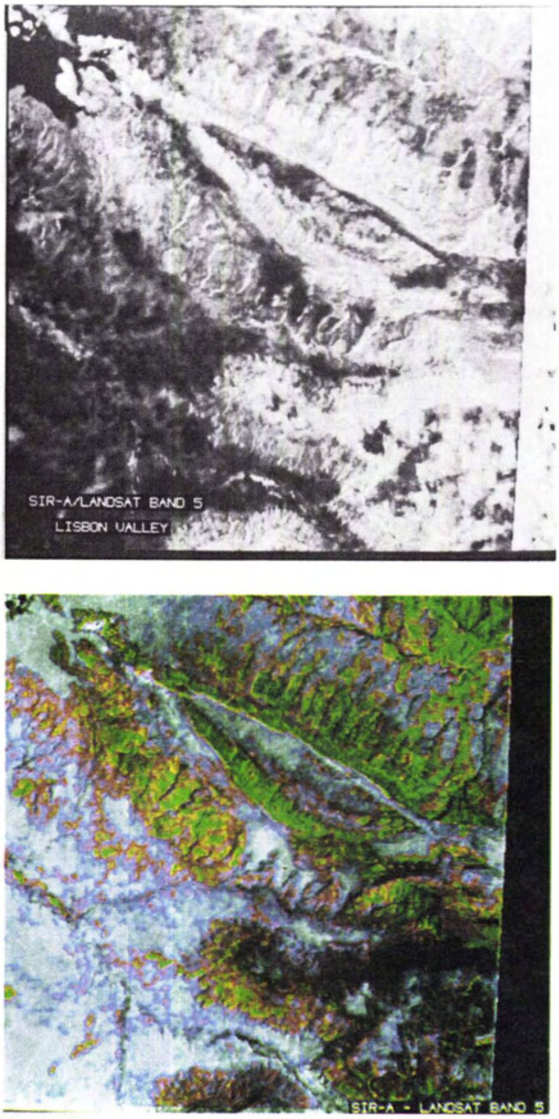

PLATE 4. Combined SIR-A/Landsat band 5 imagery. Ratio (upper) and color (lower).

recorded in areas where the slope face is not perpendicular to the beam direction. This suggests that the upper unit is also rougher than the lower unit, perhaps related to the higher percentage of sandstone beds in the upper unit.

The Cutler Formation is represented by two gray tones or colors on the images, but is generally distinguishable from the adjacent rock units in either case. The difference in signal return from rocks of the same formation appears to be related to an abrupt change in topography. One area where the Cutler Formation is not readily distinguishable from an adjacent unit is along its southernmost contact with the Hermosa Formation. The distinction is most difficult on the ratio images, which may indicate that the MSS data interfere with the SIR-A data if combined as a ratio. However, this type of interference was not observed elsewhere in the images and, therefore, is regarded as a negligible consequence of the ratio process.

Of the various combinations studied, the IHS-controlled color images are believed to represent the best method for displaying the information from both sensors simultaneously. As Table 1 indicates, a higher degree of distinction between adjacent rock units was obtained using this method. For the majority of units in the area, discrimination was facilitated using the color images as opposed to using the filtered SIR-A or ratio images alone. In part, this improvement resulted from fewer judgement decisions needed in the identification process. For example, the difference between pink and green on the color images is often decidedly more apparent than the corresponding difference between dark gray and medium gray on the filtered SIR-A or ratio images

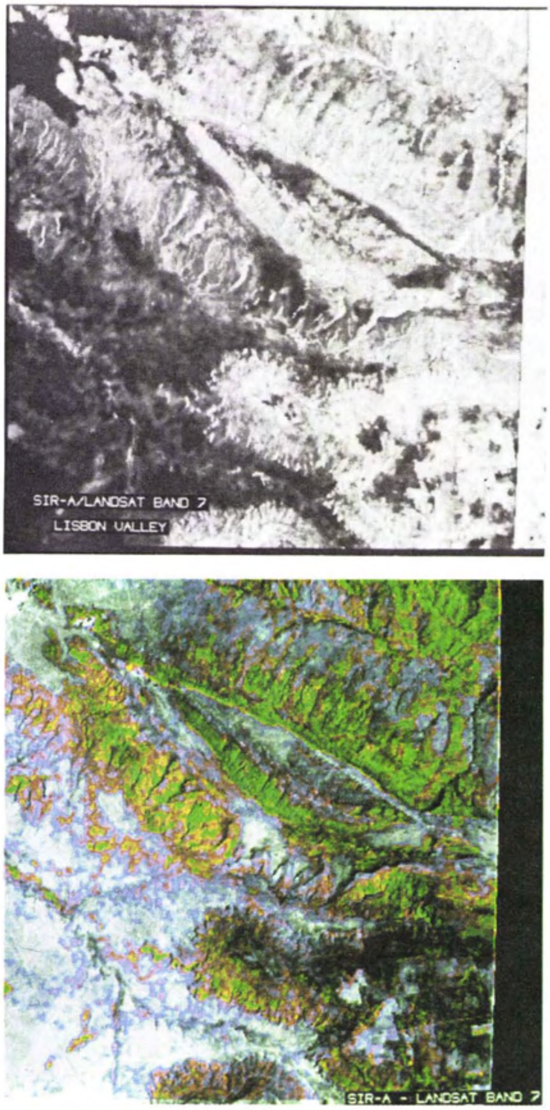

PLATE 5. Combined SIR-A/Landsat band 7 imagery. Ratio (upper) and color (lower).

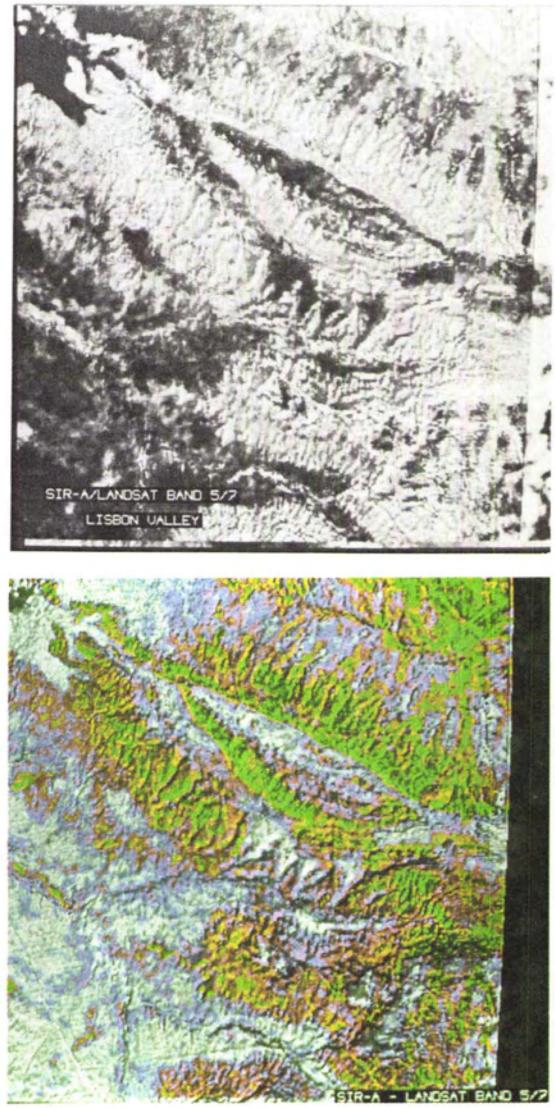

PLATE 6. Combined SIR-A/Landsat band 5/7 imagery. Ratio (upper) and color (lower).

(see, for example, the boundary between the Navajo Sandstone and the Kayenta and Wingate Formations).

In a manner similar to that described for the ratio images, the Landsat MSS data contribute textural information which is often characteristic of a particular rock unit on the color images. Unlike the ratio images, however, these data are less likely to interfere with the SIR-A data because the SIR-A brightness values (which control hue and saturation) vary independently of the MSS values (see IHS section). Consequently, the colors corresponding to a specific range of SIR-A image tones necessarily remain constant throughout the scene. This condition is beneficial because it prevents the alteration of any original image tonal differences. On the resulting image, the information contributed by each sensor can be distinguished and evaluated as such.

SUMMARY

The SIR-A system parameters, such as wavelength, depression angle, and resolution, are adequate for discriminating most of the rock units in the study area. The majority of the units that cannot be distinguished on the radar image are located in areas of smooth (relative to the 23.5-cm wavelength of the L-band radar), low-relief topography.

An effective method of enhancing the SIR-A imagery for geological mapping combines the radar data with data from the Landsat multispectral scanner. Digital registration of the two images was facilitated inasmuch as the severe distortions encountered in imagery generated by airborne systems are not encountered in imagery generated by the SIR-A system. An IHS-controlled color combination was found to be the best method for displaying the rock-type discrimination capabilities of computer-enhanced SIR-A imagery.

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