EXPRESSION OF SAN ANDREAS FAULT ON SEASAT RADAR IMAGE

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ABSTRACT

On a Seasat image (23.5-cm wavelength) of the Durmid Hills in southern California, the San Andreas fault is expressed as a prominent southeast-trending tonal lineament that is bright on the southwest side and dark on the northeast side. Field investigation established that the bright signature corresponds to outcrops of the Borrego Formation, which weathers to a rough surface. The dark signature corresponds to sand and silt deposits of Lake Coahuila which are smooth at the wavelength of the Seasat radar. These signatures and field characteristics agree with calculations of the smooth and rough radar criteria. On Landsat and Skylab images of the Durmid Hills, the Borrego and Lake Coahuila surfaces have similar bright tones and the San Andreas fault is not detectable. On a side-looking airborne radar image (0.86-cm wavelength), both the Borrego and Lake Coahuila surfaces appear rough, which results in bright signatures on both sides of the San Andreas fault. Because of this lack of roughness contrast, the fault cannot be distinguished. The wavelength of the Seasat radar system is well suited for mapping geologic features in the Durmid Hills that are obscure on other remote sensing images.

I. BACKGROUND AND OBJECTIVES

On September 14, 1978, the Seasat satellite acquired a strip of L-Band radar imagery (23.5-cm wavelength) that was processed at the Jet Propulsion Laboratory and includes the eastern margin of the Salton Sea in southern California (Figure 1). Examination of the image revealed a prominent tonal lineament in the Durmid Hills and this portion of the image, indicated in Figure 1, was selected for detailed study. The objectives of the study were to (1) determine the cause of the contrasting signatures on opposite sides of the lineament, (2) evaluate the geologic significance of the lineament, and (3) compare the Seasat image with other remote sensing images.

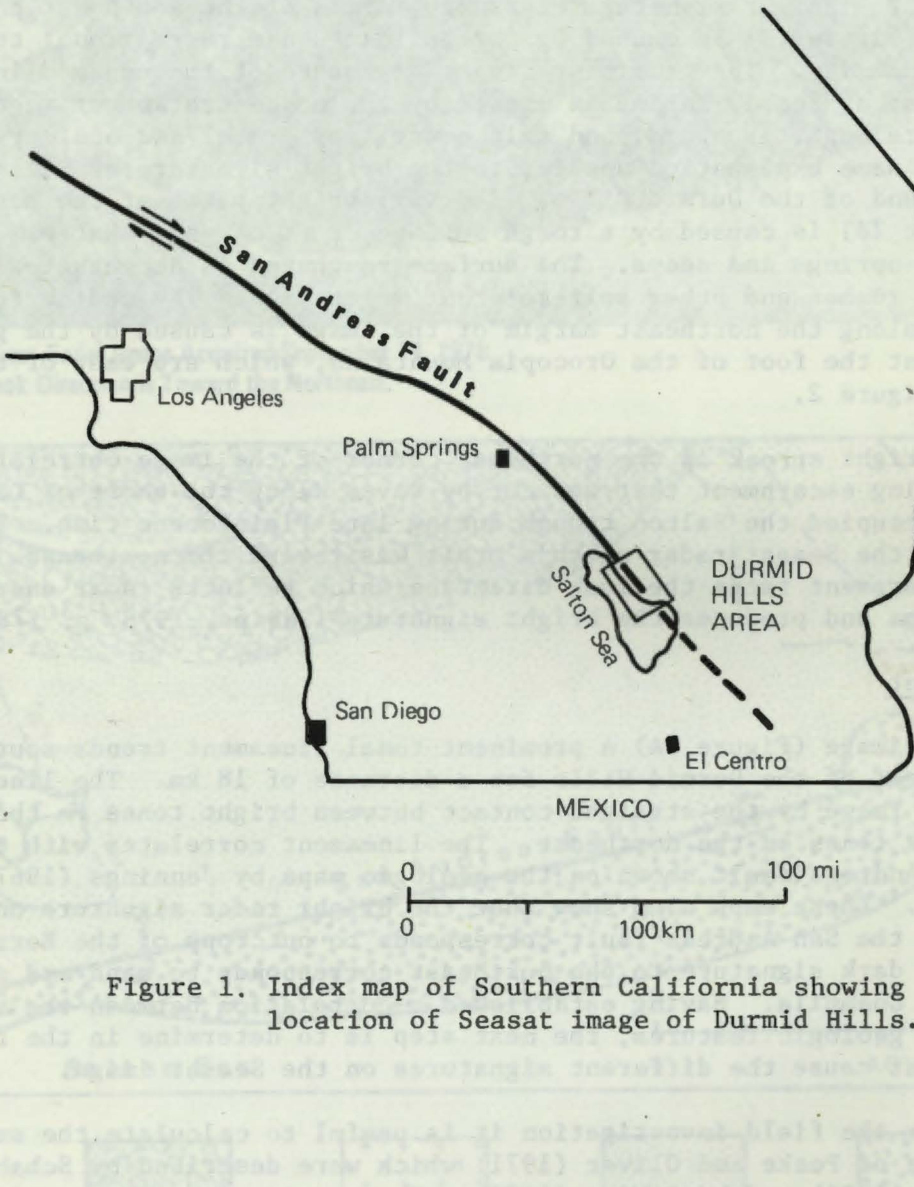


Figure 1. Index map of Southern California showing location of Seasat image of Durmid Hills.

II. SEASAT IMAGE

The Seasat image of the Durmid Hills (Figure 2A) has been greatly enlarged photographically, which accounts for the grainy, or speckled, appearance. The image has not been enhanced by digital processing methods.

A. General Description

The bright signature of the Salton Sea in Figure 2A is caused by the steep depression angle (67° to 73°) of the Seasat radar and the small ripples that prevail on the sea. The bright signature of Bombay Marina at the southeast end of the Durmid Hills (Figure 2B) is caused by the buildings and recreational trailers at this resort community. The prominent bright signature of the unnamed intermittent stream east of Bombay Marina is caused by the concentration of vegetation (mesquite, creosote bush, ironwood, and salt cedar) and gravel and boulders in the channel. The same explanation applies to the bright signature of Salt Creek at the northwest end of the Durmid Hills. The very bright patch at the head of Salt Creek (Figure 2B) is caused by a rough surface crust of salt that has evaporated from saline springs and seeps. The surface roughness is accentuated by a dense growth of rushes and other salt-tolerant vegetation. The medium-to-bright signature along the northeast margin of the image is caused by the gravel of alluvial fans at the foot of the Orocopia Mountains, which are east of the area covered by Figure 2.

The arcuate bright streak in the northeast corner of the image correlates with the west-facing escarpment that was cut by waves along the shore of Lake Coahuila, which occupied the Salton trough during late Pleistocene time. The look direction of the Seasat radar on this orbit was toward the northeast. The Lake Coahuila escarpment faces the look direction which reflects radar energy back to the antenna and produces the bright signature (Sabins, 1978, p. 178).

B. Radar Lineament

On the Seasat image (Figure 2A) a prominent tonal lineament trends southeastward along the crest of the Durmid Hills for a distance of 18 km. The lineament is defined on the image by the straight contact between bright tones on the southwest side and dark tones on the northeast. The lineament correlates with the trace of the San Andreas fault shown on the geologic maps by Jennings (1967) and by Babcock (1974). These maps also show that the bright radar signature on the southwest side of the San Andreas fault corresponds to outcrops of the Borrego Formation and the dark signature to the northeast corresponds to sand and silt deposited in Lake Coahuila. Having established a correlation between the radar lineament and the geologic features, the next step is to determine in the field the properties that cause the different signatures on the Seasat image.

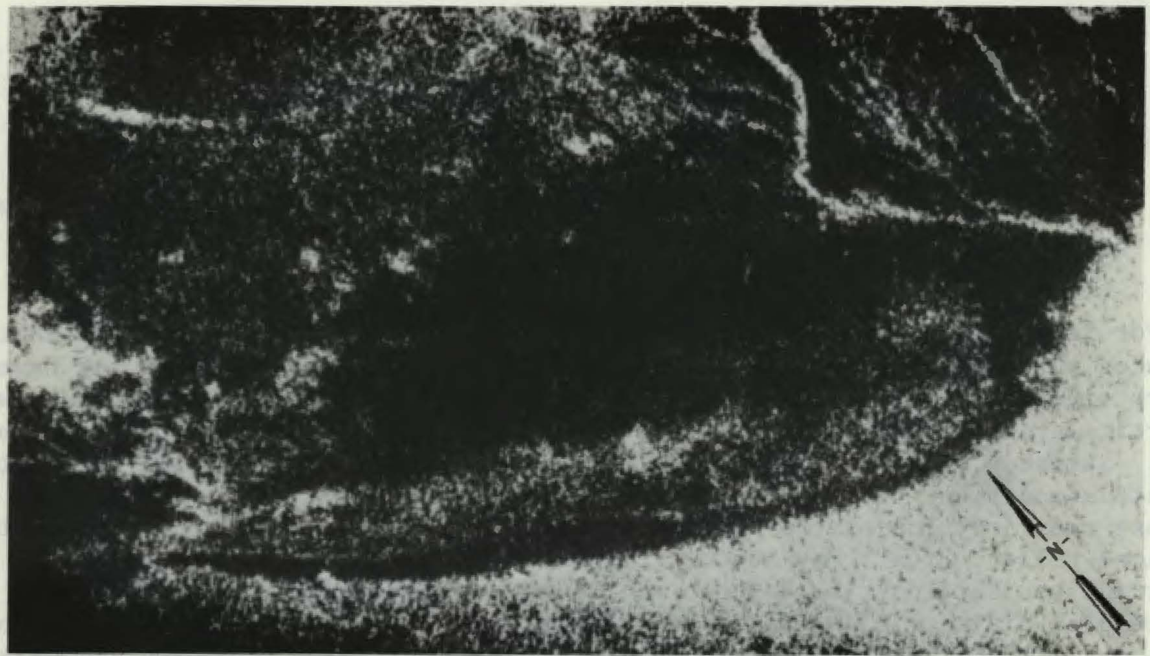
As a guide for the field investigation it is useful to calculate the smooth and rough criteria of Peake and Oliver (1971) which were described by Schaber, Berlin, and Brown (1976) and by Sabins (1978). These criteria are:

Smooth Criterion

$$h < \frac{\lambda}{25 \sin \gamma}$$

Rough Criterion

$$h > \frac{\lambda}{4.4 \sin \gamma}$$



A. Seasat Radar Image Acquired September 14, 1978
Look Direction is Toward the Northeast.

B. Interpretation Map

Figure 2. Seasat image and interpretation map.

where

h = the average height of surface irregularities, or surface roughness

λ = the radar wavelength, which is 23.5 cm for Seasat

γ = the depression angle between the horizontal plane and the radar wave incident upon the terrain. For Seasat the average depression angle is 70°.

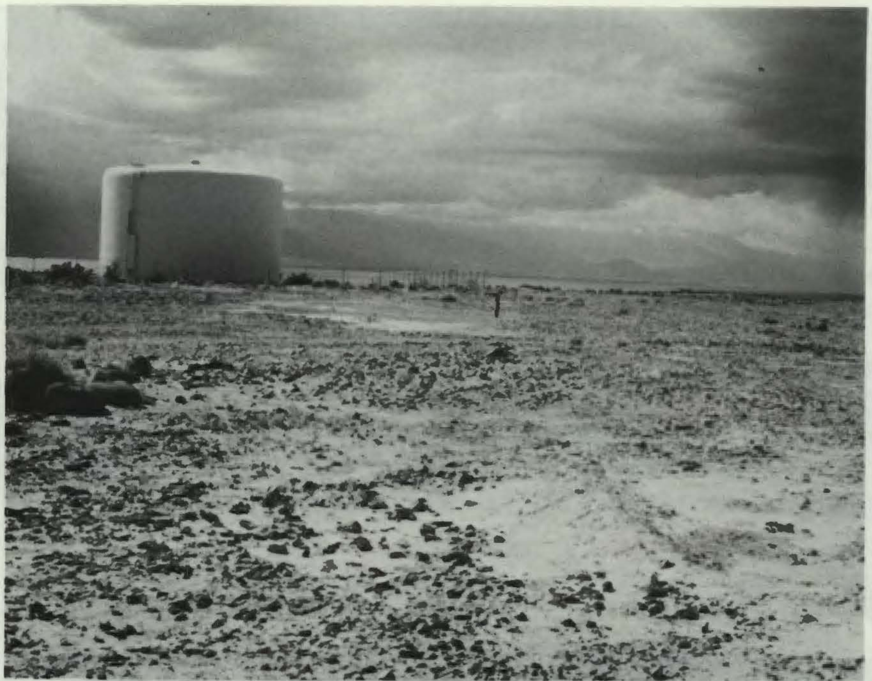
For Seasat the smooth criterion is calculated as 1.0 cm, which means that surfaces with a vertical relief of 1.0 cm or less will appear smooth and have a dark signature. The rough criterion is 5.7 cm, which means that surfaces with a vertical relief of 5.7 cm or more will appear rough and have a bright signature. Surfaces with vertical relief ranging from 1.0 to 5.7 cm will have intermediate signatures. These roughness values are for comparative purposes, because radar returns are influenced by many surface properties in addition to vertical relief. The shape and horizontal spacing of surface features are important but difficult to describe in a quantitative manner. Variations in the complex dielectric constant, principally due to variations in moisture content, may also influence the strength of the radar return (MacDonald and Waite, 1973, p. 149).

C. Field Investigation

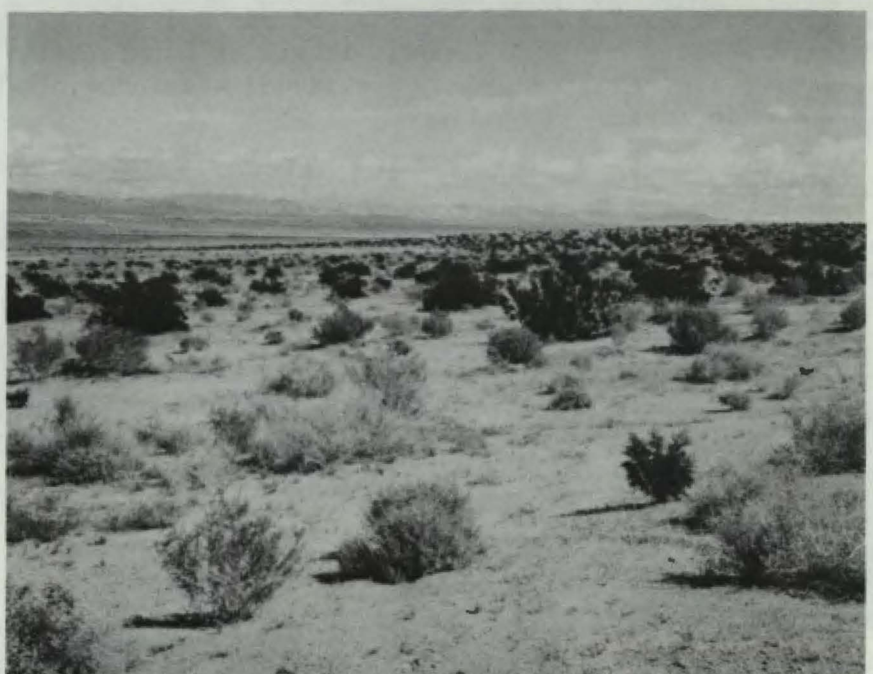
Topographic maps, stereo aerial photographs, and field observations show that the Durmid Hills are a low, southeast-trending ridge with slopes of 2° or less. The maximum elevation is 30 m and the minimum elevation is 70 m below sea level at the shore of the Salton Sea. Vegetation is very scarce in this arid climate.

The Borrego Formation (Pleistocene age) crops out on the southwest side of the San Andreas fault (Figure 2B) and consists of poorly consolidated siltstone with minor beds and concretions of hard, resistant sandstone. The infrequent rains erode the soft siltstone and produce a surface that is littered with fragments and concretions of sandstone that range from gravel to boulders in size (Figure 3A). The local relief of this detritus is well in excess of the 5.7-cm criterion for a rough surface on Seasat images, which agrees with the bright signature of the Borrego outcrop in Figure 2A. The roughness of the Borrego surface is increased by a myriad of closely spaced, steep-walled gullies. The Borrego siltstone is impermeable, which causes rainfall to run off rather than soak into the ground. The combination of high surface runoff and nonresistant bedrock results in a highly dissected surface.

The surface northeast of the San Andreas fault is covered by unconsolidated sand and silt deposited in Lake Coahuila (Figure 2B), which occupied the Salton trough in Pleistocene time. As shown in the photograph of Figure 3B, relief of this surface is less than the 1.0-cm value for the smooth criterion, which accounts for the dark signature on the Seasat image. Gullies are scarce on the Coahuila surface because the permeable sand and silt absorb most of the rainfall. Creosote bush and other desert shrubs are scattered over the Coahuila surface but are too sparse to influence the radar signature.



A. Outcrop of Borrego Formation on Southwest Side of San Andreas Fault. The Boulders and Cobbles Form a Rough Surface That Has a Bright Signature on the Seasat Radar Image.



B. Sand and Silt Deposits of Lake Coahuila on Northeast Side of San Andreas Fault. These Deposits Form a Relatively Smooth Surface That Has a Dark Signature on the Seasat Radar Image.

Figure 3. Outcrop photographs in the Durmid Hills.

The field observations and radar calculations explain the bright and dark signatures on opposing sides of the Seasat lineament that corresponds to the San Andreas fault. In the field the fault trace is relatively obscure and is marked by the contact between Borrego outcrops and the Coahuila surface. In the Durmid Hills the San Andreas fault is not marked by topographic features such as scarps, sag ponds, and pressure ridges. If these features were formed by displacement along the fault, they have later been removed by erosion of the nonresistant rocks. Babcock (1974, Figure 5) mapped outcrops of Borrego Formation on the northeast side of the San Andreas fault, but these are largely mantled by thin deposits of Coahuila sand and silt, which produce a relatively smooth surface.

III. COMPARISON OF IMAGES

It is instructive to compare the Seasat image with images that were acquired by other remote sensing systems. The Landsat and Skylab images (Figure 4) and the aircraft radar image (Figure 5) are reproduced at the same scale as the Seasat image.

A. Landsat Image

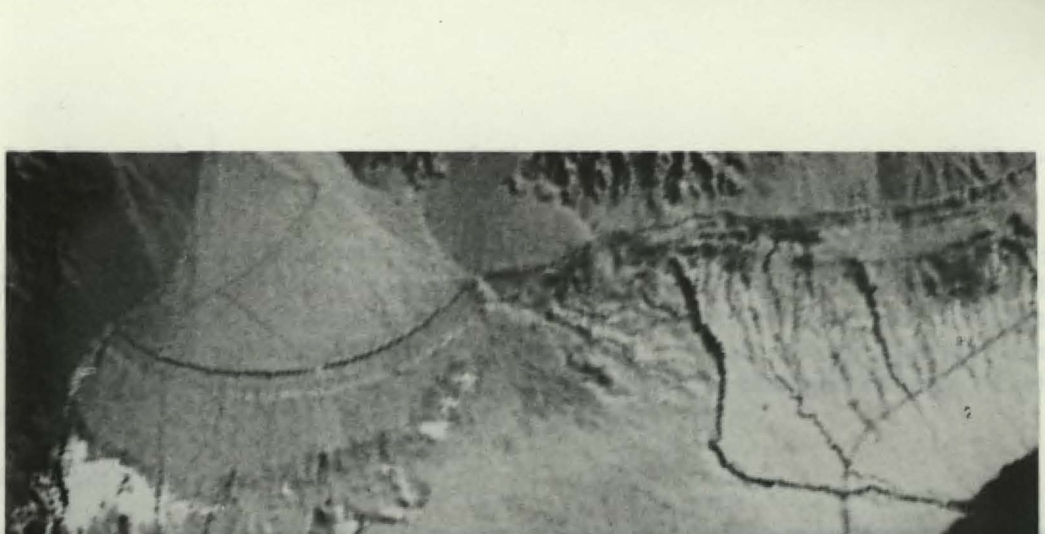
The red image (band 5) of Landsat (Figure 4A) was selected because this band has the maximum tonal contrast in the Durmid Hills area. The image was digitally processed at the EROS Data Center to improve the contrast and spatial detail. Water in the Salton Sea and Coachella Canal has a dark signature, as do the water and vegetation in Salt Creek and the unnamed creek near Bombay Marina. The dark trace parallel with the shoreline is formed by Highway 111 and the Southern Pacific Railroad. On the Landsat image there is no tonal difference between the Borrego and Coahuila surfaces, and the San Andreas fault cannot be recognized. Infrared-color composite Landsat images of Durmid Hills (not illustrated here) were also examined, but no evidence was found of the fault or of the differences in surface materials.

B. Skylab Photograph

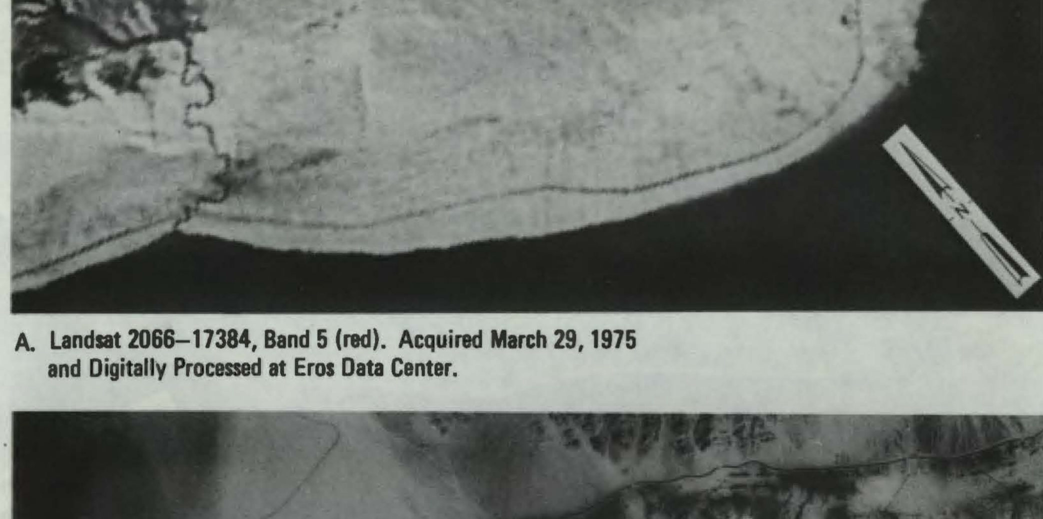
The Skylab earth terrain camera photograph (Figure 4B) was acquired in the reflected infrared band and has a spatial resolution of approximately 15 m in contrast to the 80-m resolution of Landsat images. Aside from the higher resolution of the Skylab photograph, there is little difference in appearance of the two images. The Skylab photograph has no discernible tonal difference between the Borrego and Coahuila surfaces, and the San Andreas fault is not recognizable. There is an area of medium gray tone on the northeast flank of the Durmid Hills, but this is an area of reduced reflectance within the Coahuila surface that is not related to the fault contact.

C. Aircraft Radar Image

The side-looking airborne radar image (Figure 5) was acquired at a wavelength of 0.86 cm and an average depression angle of 45°. For this image the smooth criterion is calculated as 0.05 cm and the rough criterion as 0.28 cm. Most natural surfaces, other than calm water, are rough for these criteria, and this is seen in the overall bright appearance of the image (Figure 5). Even the sands of the Coahuila surface are rough and produce a bright signature that is indistinguishable from the Borrego surface. Because of this lack of tonal contrast, the San Andreas fault cannot be recognized on the short-wavelength radar



A. Landsat 2066–17384, Band 5 (red). Acquired March 29, 1975 and Digitally Processed at Eros Data Center.



B. Skylab–3 Infrared Black–and–White Photograph Acquired September 10, 1973 With Earth Terrain Camera (S–190B).

Figure 4. Landsat and Skylab images of Durmid Hills.

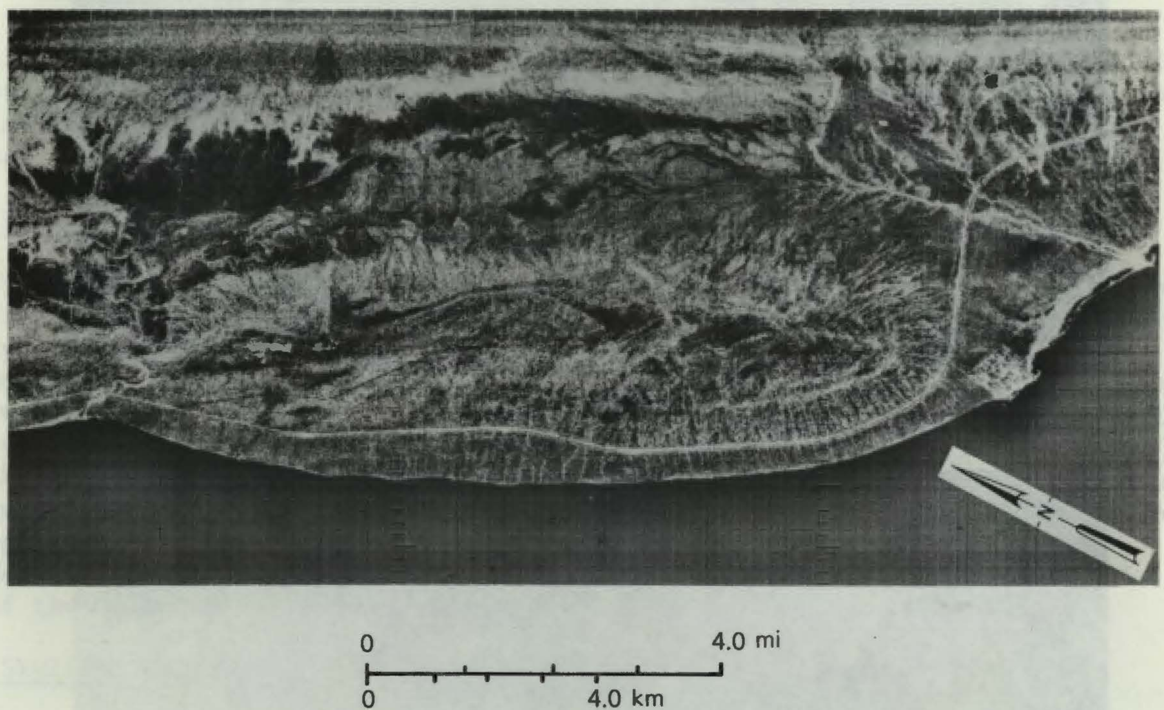


Figure 5. Real aperture side-looking airborne radar image. This Ka-band image (wavelength = 0.86 cm) was acquired in November 1965. Radar look direction is toward the southwest. Image courtesy NASA and U.S. Geological Survey.

image. In the northeastern portion of the image are some patches of fine-grained sediment within the Coahuila deposits that produce dark signatures.

The airborne radar image was acquired at a short wavelength and relatively low flight altitude (approximately 6000 m) which results in a relatively high spatial resolution of approximately 10 m. The high resolution and optimum depression angle enable individual gullies to be recognized on the southwest flank of the Durmid Hills. These gullies are not discernible on any of the other images.

IV. SUMMARY AND CONCLUSIONS

The wavelength of the Seasat radar (23.5 cm) is optimum for producing contrasting image signatures of surface materials juxtaposed along the San Andreas fault in the Durmid Hills. Erosion of the Borrego Formation on the southwest side of the fault produces a surface that appears rough at the Seasat wavelength and has a bright signature on the image. Sand and silt deposits of Lake Coahuila on the northeast side of the fault are relatively smooth and produce a dark signature. The San Andreas fault is clearly expressed on the Seasat image as a southeast-trending tonal lineament that is bright on the southwest side and dark on the northeast. The San Andreas fault is not distinguishable on Landsat and Skylab images of the Durmid Hills because the Borrego Formation and the Coahuila deposits have a relatively high albedo and do not produce contrasting signatures at these visible and photographic infrared wavelengths. An airborne radar image was acquired at a very short wavelength; therefore, both the Borrego Formation and the Coahuila deposits appear rough. As a result, on the airborne radar image the signatures are bright on both sides of the fault and there is no tonal contrast.

The geologic cause for the juxtaposition of the Borrego Formation and Lake Coahuila deposits along the San Andreas fault has not been determined. The two most probably hypotheses are: (1) in Coahuila time the fault formed a topographic scarp that restricted deposition of Coahuila sediments to the northeast side of the fault, or, (2) in post-Coahuila time, uplift of the southwest side of the fault resulted in erosion of Coahuila deposits and exposure of Borrego outcrops on that side of the fault.

In summary, although the Seasat radar system was designed for oceanographic applications, it does have a capability for geologic mapping in suitable terrain. These Seasat observations suggest that geologically useful information will be obtained from future orbital radar missions, such as the Space-Imaging Radar (SIR-A) Mission of Space Shuttle.

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