

Remote Detection of Culturally Disturbed
Sites in Bandelier National Monument

by

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I. Introduction

A. Background

In October, 1976 the National Park Service, Office of Contract Archeology, arranged for a Bendix* 11-channel M²S scanner to be flown over several archeological areas in New Mexico. Their purpose was to evaluate airborne spectral data as a means for non-destructive exploration of Anasazi and pueblo cultural sites in Chaco Canyon, Bandelier National Monument, Cochiti and Garcia Canyon areas. In a previous paper, Morain et.al., (1977) presented an analysis of the Chaco Canyon data. That report focused on image processing techniques to enhance such features as prehistoric agricultural fields, anthropogenic soil patterns, buried walls and kivas, and prehistoric road traces. It was essentially a description of the range of enhancement capabilities using a hard-wired General Electric Image 100. The analyses included contrast stretching, band ratioing, high and low band pass filtering, color compositing and single class color enhancing.

From the experience gained at Chaco Canyon a follow-on experiment was undertaken to assess culturally disturbed sites at Bandelier National Monument. The aim of this effort was to subject the MSS data to both supervised and unsupervised classification strategies in a further test of image analysis for cultural information. Principal components and canonical

* Early in 1978 the Bendix Aerospace Division at Ann Arbor was acquired by the Environmental Research Institute of Michigan (ERIM).

analyses were performed on an identical 512 scan line x 512 sample data matrix. Since each resolution cell (pixel) was about 3.75 feet² (1.25 m²), the subscene covered an area of about 1920 feet (585 m) on a side (0.13 sq mi or .34 sq km). Within this area several culturally disturbed sites were known to exist by virtue of their presence on the USGS 1:24,000 Frijoles quadrangle.

B. Problem Statement

The basic study question was whether the classification strategies were capable of spectrally separating known culturally disturbed sites from surrounding terrain categories. Equally important we wanted to know whether additional, unmapped sites might be revealed through these procedures. Analytically, we were interested in discovering whether the unsupervised or supervised strategy gave more readily interpretable results. The intent of the investigation was more sophisticated than that performed at Chaco Canyon in that the procedures were rooted in statistical probabilities rather than relatively simple algebraic functions based on the manipulation of pixel digital counts.

The reason for using more involved algorithms to analyze the environment at Bandelier National Monument lay partly in the subtlety of the features under study. The sites plotted on the topographic quadrangle are implied to be "ruins." This suggests that there are remains of structures; or, that there is at least a prospect for finding buried foundations, walls or complexes. In fact, however, human occupancy at Bandelier,

as at most archeological sites, spanned a range of activities only a few of which resulted in lasting structures or their ruins. To avoid connotations that our procedures and results might apply solely to such structures and not to other human impacts, we have adopted the phraseology "culturally disturbed" sites. Our hypothesis was that human disturbance of the environment could be detected through spectral analysis. In order to be detected, such disturbance would have to have been localized and prolonged, or brief but very intense. In terms of remote sensing this problem is not dissimilar to that in either agriculture or forestry where stress and pest infestations must be locally intense to be spectrally identifiable using systems with relatively coarse spatial resolution. An adverse consequence of our phraseology, however, is that, if intensely disturbed sites are detectable, we have no *a priori* knowledge as to the nature of the disturbance. Field checking alone would have to enlighten us on that matter.

II. Cultural Disturbance at Bandelier

A. The Physical Environment

Bandelier National Monument is located near Los Alamos in the Jemez Mountains of north-central New Mexico (Figure 1). Casual tourists to the area are familiar with the extensive ruin complexes in Frijoles Canyon where the Monument headquarters are located (Figure 2). However, on the mesas between Frijoles, Alamo and Capulin Canyons, west of the headquarters, there are hundreds of local and much less spectacular archeological sites. Aside from Monument personnel, only a few

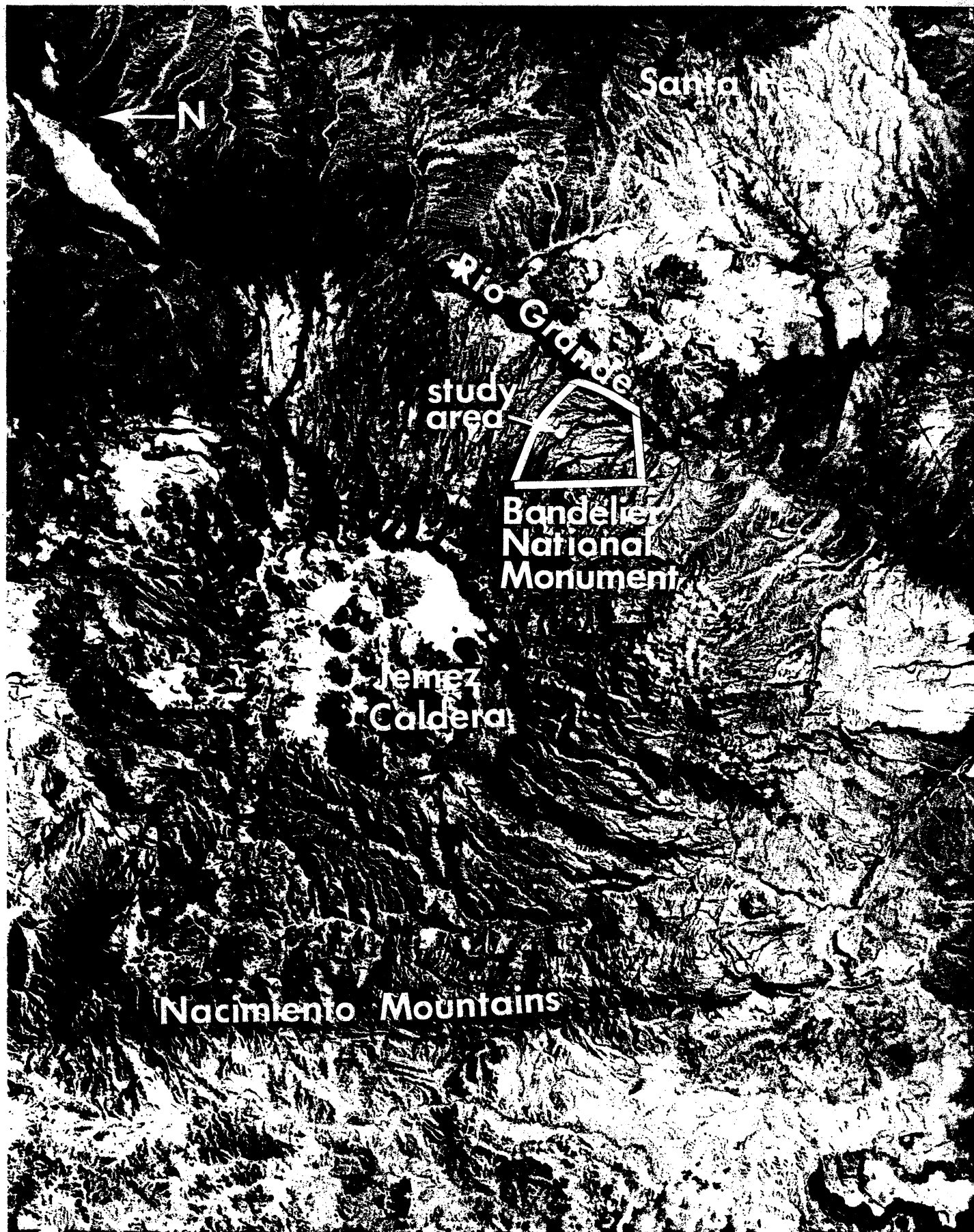


Figure 1: Location of Bandelier National Monument



Figure 2: Tyuonyi ruins in Frijoles Canyon are one of the most impressive sites in the Rio Grande drainage. These ruins are the closest to Bandelier headquarters and are among the most frequently visited of the ancient pueblo ruins.

determined backpackers ever see these, partly because the area is closely protected and because the canyons have exceedingly steep walls that prohibit access. Figure 3 is part of the Frijoles quadrangle showing the general location of Bandelier Monument headquarters and the locale for the present study.

The mesas southeast of Jemez Caldera are formed from thick and complex deposits of volcanic tuff and ash blown from the Jemez volcano over a period of a million years or more. These materials are relatively soft and porous. Hence, they have been dissected by steep canyons. Soil development and organic build-up over much of the surface has been negligible so that the background albedo is high and is attributed to the tuff itself.

Precipitation in the region averages sixteen inches (400 mm) per annum. The porous nature of the bedrock combined with high evapotranspiration (summer high temperatures exceed 80°F or 23°C), results in a low amount of moisture for plant growth. Throughout the mesa/canyon complex below about 6500 feet, the vegetation consists of piñon-juniper (Pinus edulis - Juniperus spp.) woodlands with occasional ponderosa pine (P. ponderosa) and small grassy clearings. Total cover in the overstory trees, as interpreted from a crown density scale from 1975 forest service photography, averages less than 35-45%. The trees display a tendency towards contageous*

* "contageous" is used here to describe patches or clusters of trees. See Dictionary of Ecology, Herbert C. Hanson, 1962.

35°47'

35°45'
106°15'

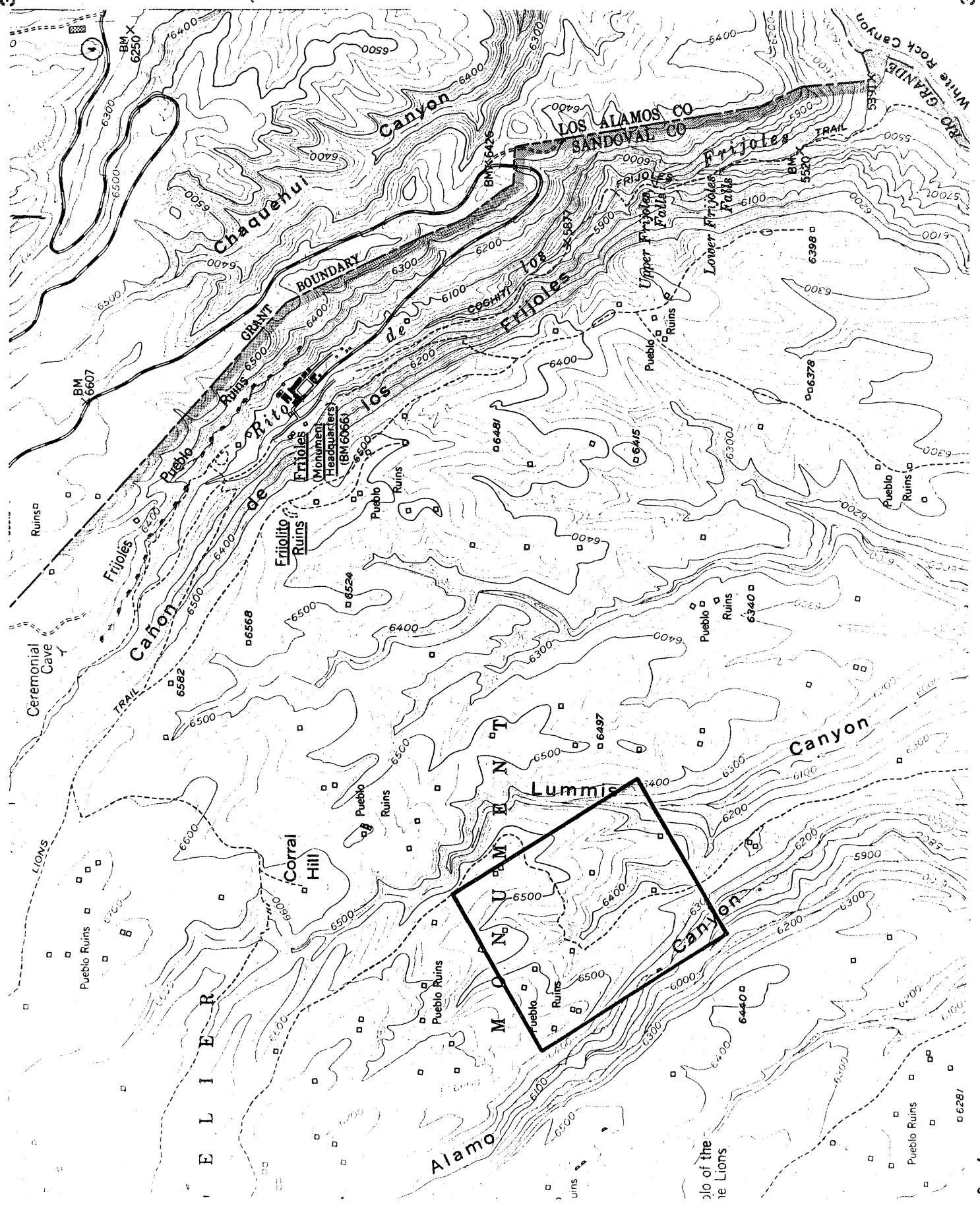


Figure 3: Location of study site in Bandelier National Monument

106°18'

distribution. Ground cover is equally open, if not more sparse. Along the upland drainage lines, and in swales, one can find local concentrations of great basin sage (Artemisia tridentata) and rubber rabbit brush (Chrysothamnus spp.). These stands tend to be somewhat more dense and in some cases may approach complete cover.

B. Site Variability

A field visit to about one dozen cultural sites southeast of the Monument headquarters was made prior to data analysis. They provide a basis for describing the range of variability found in disturbed areas. The places visited included Frijolito, one of the few named ruins, and a series of easily accessible but subtle unmarked sites that had to be explored. Figure 4 gives typical views of the appearance of these sites in the field. These localities are frequently identifiable by the presence of small pot sherds and occasional building stones, but otherwise look like the surrounding countryside. Walls and wall fragments are infrequent so that the untrained eye would probably not distinguish any level of former cultural activity.

Following the analysis, field visits were made to the series of sites contained within the 512 x 512 subscene investigated. Additional potential sites revealed by the analysis were also explored to verify their reality. The results of this effort are described in section IV.



Culturally Disturbed Site



Ruin



Culturally Disturbed Site



Ruin

Figure 4: Typical views of culturally disturbed sites on the mesa west of Frijolito Canyon. Note the sparse vegetation and high surface albedo.

We estimate from field observations that the most intensely disturbed sites range in diameter from 25 to 40 feet (7.6 - 12.2 m). With the given resolution of 3.75 foot, this means that our analysis for any given site involved anywhere from 30 to 90 independent spectral samples (pixels). The smaller sites were close to the lower limit of statistical reliability but the larger sites were well above that limit.

Two or three items regarding the spectral and spatial appearance of disturbed sites should be noted. First we have observed that few sites are inhabited by either piñon or juniper. Sites generally have a sparse cover of bunch grass or are essentially barren. One could therefore anticipate difficulty trying to distinguish such areas from natural terrain classes called "grass" or "bare soil." Secondly, sites are occasionally ringed by piñon and/or juniper. In this condition they may be visually highlighted through photo context, but not particularly distinguishable through current image processing strategies that use only spectral properties as variables. Thirdly, we have observed that disturbed sites located on ridges or low drainage divides often have remnants of walls or evidence of other structures. We assume these were dwellings located on somewhat higher ground for reasons of protection. Sites located off the higher ground may well have been used for other purposes. Again, this has no particular bearing on spectral differentiation but may be useful, if the analysis were to include stereoscopic photo interpretation.

III. Data and Methods

Morain et.al., (1977) have described the Bendix data characteristics in detail. A summary of the sensor specifications compared to other MSS systems is given in Appendix A. The M²S scanner operated in the wavelength range from ultraviolet to thermal infrared. At the time of data acquisition, the ultraviolet channel was not fully functional, so only 10 channels of useable data were acquired. The system has a 2.5 milliradian field of view and was flown at 1500 feet (457 m) to provide a ground resolution of 3.75 feet (1.25 m). The data used in our assessment of culturally disturbed sites consisted, therefore, of a 10 element vector for each 3.75 foot piece of terrain.

Two automatic classification algorithms were used in the analysis. A principal components analysis, described as "unsupervised," was conducted to see if cultural sites could be spectrally discriminated without *a priori* knowledge or without making any assumptions about the landscape. If they could be, then this fact would be strong evidence that early Indian occupation sites inherited long lasting spectral attributes. In fact, most previous work in remote sensing confirms that only generically different terrain elements like water, vegetation, bare soil and possibly rock have unique spectral signatures. Distinctions finer than this almost always require the addition of ground truth and field confirmation. Our experiment with principal components is therefore viewed as a test of the null hypothesis that *culturally disturbed sites cannot be discriminated by spectral properties alone.*

The second analytical approach was a canonical analysis. This is described as "supervised" in that the spectral statistics from known sites were used to "train" the computer to distinguish predefined terrain classes. The occurrence of these classes was then predicted over the entire 512 x 512 subscene. Again, our desire was to determine if culturally disturbed sites were spectrally discriminable. But, in this case we assisted the analysis by looking at the spectral responses of known sites, and comparing their common patterns to predict their distribution over the rest of the study area. Our null hypothesis was that *culturally disturbed sites, even if sufficiently homogeneous spectrally, cannot be discriminated by extending the statistics from known samples.*

One motivation behind the above two approaches, not only in archeology but in other earth sciences, has been the desire to disprove the null hypotheses and extend the technique(s) to ever greater distances from the original study site. Regardless of our results, one should be cautious about the validity of signature extension. Ephemeral parameters of both system and terrain act synergistically to preclude extension to any great distance. What is discriminable at one study site may not be at another because of slight differences in slope, lithology, solar azimuth and elevation, and for a host of other reasons. All our conclusions must be phrased in terms of the null hypotheses. Any further conclusions have to be in terms of environmental and cultural uniformity, assuming nearly identical flying conditions and sensor performance.

A. Principal Components Analysis

The principal components analysis is a technique for transforming multivariate data into a series of uncorrelated axes. Each of the ten spectral channels is an axis of variability. The data are transformed to describe the same total variance with the same number of variables, but in such a way that the first axis accounts for as much of the total variance as possible; the second axis accounts for as much of the remaining variance as possible while being uncorrelated with the first axis; and so on. Normally this results in a few axes which account for most of the total variance and a larger number of small axes that account for very little of the total variance. Usually the smaller axes can be discounted from further consideration, but sometimes they reveal interesting attributes about the original data.

Because of the large number of data values and computations needed to create variance and co-variance matrices, it was unwieldy to work with the entire data set. In our case there were 512 x 512 resolution elements; each characterized by 10 variables....one for each spectral channel. In order to conduct an analysis without introducing bias, we selected a 20% random sample of pixels. Table 1 shows the total amount of variation "explained" by each of the axes resulting from this analysis.

These data indicate that the first three axes account for more than 96% of the variation in the spectra. The question as to which spectral channels were most important in each axis is answered by the component loadings as given in Table 2.

TABLE 1: PERCENTAGE OF VARIABILITY CONTRIBUTED
BY EACH PRINCIPAL AXIS

AXIS	1	2	3	4	5	6	7	8	9	10
% "EXPLAINED" VARIABILITY	78.76	11.34	6.18	1.58	1.01	.42	.29	.21	.14	.07
CUMULATIVE %	78.76	90.10	96.28	97.86	98.87	99.29	99.57	99.79	99.93	100.00

TABLE 2: COMPONENT LOADINGS. THESE VALUES INDICATE
THE RELATIVE IMPORTANCE OF EACH SPECTRAL
CHANNEL IN CONTRIBUTING TOWARD THE PER-
CENTAGE OF VARIABILITY ACCOUNTED FOR BY
EACH AXIS.

AXIS CHANNEL	1	2	3	4	5	6	7	8	9	10
<u>λ(nm) Color</u>										
1 465 blue	.3548	.2632	.4353	-.4474	-.6180	.0469	.0347	.1398	-.0971	.0305
2 515 green	.3156	.1418	.2154	.3481	-.0543	-.6460	-.1142	-.3253	.4160	-.0221
3 560 yellow-green	.3111	.0693	.2003	-.0164	.2935	.3857	-.1106	-.6406	-.2232	.3881
4 600 orange	.2793	.1611	.1825	.3715	.2049	-.0870	.0324	.1835	-.6528	-.4629
5 640 red-orange	.2491	.1239	.1674	-.1279	.3516	.4171	.1138	.0842	.5530	-.5047
6 680 red	.2416	.1245	.1048	.2373	.2477	.0074	.3631	.5372	.1169	.6027
7 720 reflective IR	.2409	-.2144	.0116	-.2130	.2406	-.0941	-.8054	.3534	.0084	.1004
8 815 reflective IR	.3577	-.5675	-.1152	.4613	-.4369	.3491	-.0290	.0259	.0911	-.0360
9 1015 reflective IR	.3695	-.5206	-.1441	-.4544	.2094	-.3444	.4197	-.0933	-.1167	-.0656
10 1100 thermal IR	.3958	.4582	-.7858	-.0534	-.0977	.0275	-.0447	-.0244	-.0067	-.0061

High positive and negative values are of interest. For the first axis all spectral channels seem to be important but the most important contributors were the reflective infrared channels (8 and 9), and the thermal channel (10). The reflective infrared channels were also important in the second axis in a negative way. Similarly, the importance of the thermal IR channel declines after the third axis. Beyond the sixth axis, most of the contribution seems to be coming from one or two visible channels. Much of this might be explained in terms of low signal-to-noise ratios in the detectors for those channels.

To create interpretable images from the principal components statistics, it was necessary to expand the 20% random sample back to the entire data set. Since there were no training areas used in the selection of the 20% sample, a maximum likelihood classifier was used to create a "probability" image (Figure 5); that is, we created a statistically probable image based on our understanding of the spectral response of 525 randomly distributed points. The classifier operated by assigning each picture element to one of 15 grey scale classes based on the statistics of the nearest random samples.

The darkest value has a probability of correct assignment (or confidence limit) of 99%, while the highest values have a 0% confidence. A qualitative interpretation of Figure 5 suggests that a sufficient number of pixels have been confidently assigned to at least produce an image resembling the original. However only about 30-40% of the pixels have confidence limits above 50%. We interpret this to mean that



Figure 5: "Probability" image based on a maximum likelihood classifier. The darkest values have a probability of correct assignment of 99%; the lightest values have a 0% confidence.

individual images produced for each of the components (Figure 6) will also have a relatively low reliability.

Using the principal component images as input to standard color enhancement procedures, color composite images were produced. For example, Figure 7 is a composite of component numbers 1, 4, and 5 displayed in blue, green and red respectively. Individual trees and open areas can be discerned; the latter, in particular, show as a rainbow of colors. Comparison of the pattern with known locations for culturally disturbed sites however, is disappointing. Furthermore, we found no combination of three components that gave a more interpretable image than that shown in Figure 7. Based on this observation our conclusion is that the null hypothesis cannot be rejected. In other words, there appears to be no uniquely discriminable spectral signature for culturally disturbed areas using this data set and an unsupervised approach.

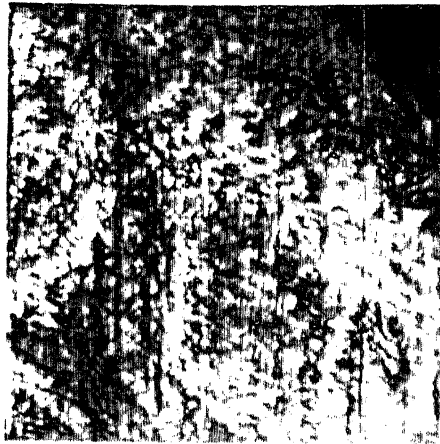
Canonical Analysis

An alternative to randomly sampling a data set for clues about its content is to pre-define classes into which the data will be partitioned. The canonical analysis is a particularly useful tool for interpreting the spatial content of images because it requires two sets of multivariate data....a training set and a predictor set. The means, standard deviations, variance and covariance matrices, etc. of training sites and predictor areas are calculated, then statistically compared for their common attributes.

For our analysis nine areas were used as training sites (Figure 8). Four of these were chosen because they coincided



#1 78.76%



#2 11.34%



#3 6.18%



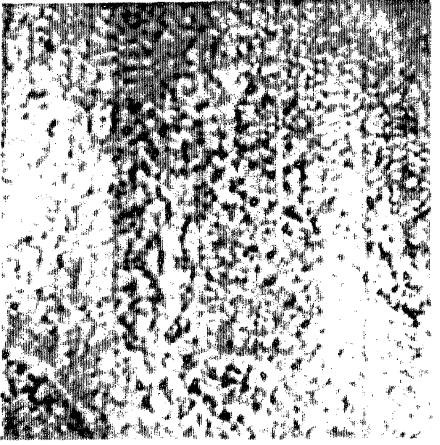
#4 1.58%



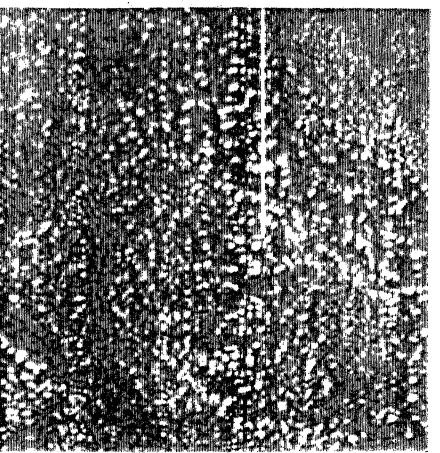
#5 1.01%



#6 0.42%



#7 0.29%



#8 0.21%

Figure 6: Principal Components



Figure 7: Components 1, 4 and 5 displayed in blue, green and red respectively. Though colorful, the image fails to provide useful information on culturally disturbed sites.



Figure 8: Nine training areas were chosen by using an electronic cursor to delineate terrain classes. Numbers 1, 2, 3, 4 are culturally disturbed sites; 5 is defined as "cliff"; 6 is "bare soil"; 7 and 8 are "tree" types; and 9 is "grass". Site 2 had the smallest number of pixels (25) and site 6 had the largest (337). The average number was 118 pixels.

with plotted positions for cultural sites on the Frijoles quadrangle. In addition, two types of tree category were delineated, and one each for "cliff," "bare soil" and "grass." In a canonical analysis the entire scene will be classified into one of the pre-selected classes, so it is important to choose sites that are representative of the scene and which, hopefully, are also spectrally separable.

As with the principal components analysis, the data are transformed into a series of uncorrelated axes in such a way as to maximize the percentage of total remaining variation in succeeding axes. In canonical analysis, however, axes are put through each of the two clusters of vectors so that they account for the maximum amount of variance within each set (training and predictor) while, at the same time, accounting for the maximum amount of covariation between each set. In our study, eight of the ten canonical axes were used; the remaining two accounted for so little variance and covariance as to be meaningless. Table 3 gives the percentages.

TABLE 3: Percentage of Variability
Contributed by Each Canonical Axis

Axis	1	2	3	4	5	6	7	8
% "explained" Variability	72.17	19.9	3.61	3.09	.76	.26	.19	.01
Cumulative %	72.17	92.07	95.68	98.77	99.53	99.79	99.98	99.99

The eight axes identify, in decreasing order of importance, the patterns common to both sets of data. A look at the separability of categories within each axis (Figure 9), shows that, in the first axis, all categories can be distinguished. The situation deteriorates in the eighth axis to virtually no separability between any of the categories. The first category of cultural site is distinctly separable in the first 3 axes. Sites 2, and 4 are separable in the first axis, but overlap in part with the "cliff" and "grass" categories in axis 2. In the third axis they are not separable. Site number 3 is separable in the first axis but overlaps with bare soil and trees in axis 2. Like sites 2 and 4, site 3 is not separable in axis 3. Whatever the nature of disturbance at site 1 it appears to be spectrally unique from other sites and terrain categories. Furthermore, the separability of sites 2, 3 and 4 in the first axis may indicate different types of past cultural activity, which, through the passage of time, have lost some of their spectral distinction. Clearly, further analysis of the data and field inspection are called for.

By comparing the statistics of the training sites to the rest of the pixels, the distribution of each category can be superimposed on a background image of the entire scene. Figure 10 shows thematic maps of the nine terrain categories displayed in different colors. All have extensive distributions except the "cliff" category (#5). This represents the darkest tones or areas of no response (shadows) in all 10 spectral channels. Category number 1 has a disappointingly broad range considering its uniqueness in the first three canonical axes.

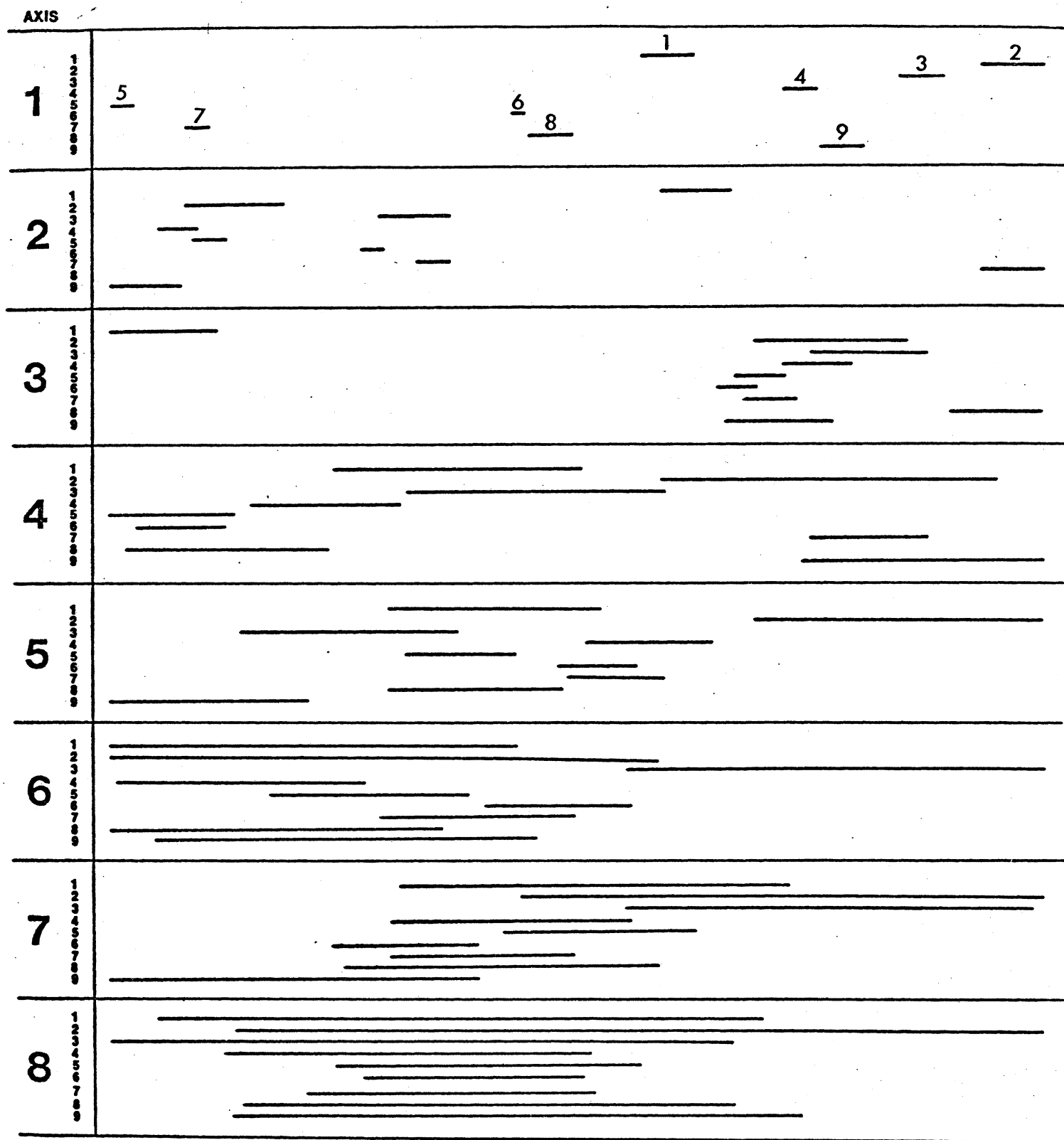
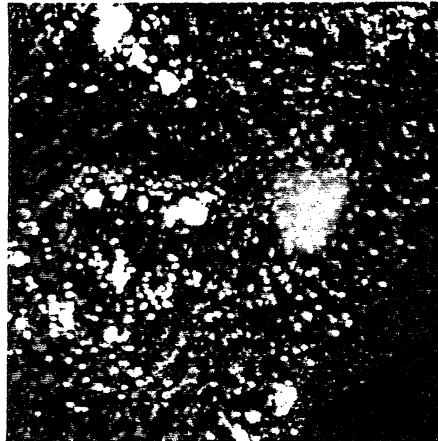


Figure 9: Canonical axes (large numbers in left column) and category separations within each axis (smaller numbers). The overlap of categories in axis 1 is minimal; whereas in 8 there is complete overlap. Categories 1, 2, 3 and 4 are defined as culturally disturbed; 5 = cliff; 6 = bare soil; 7 and 8 = trees; 9 = grass.



A. Culturally Disturbed
Category #1



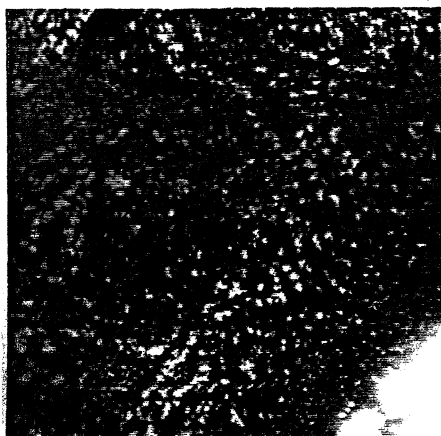
B. Culturally Disturbed
Category #2



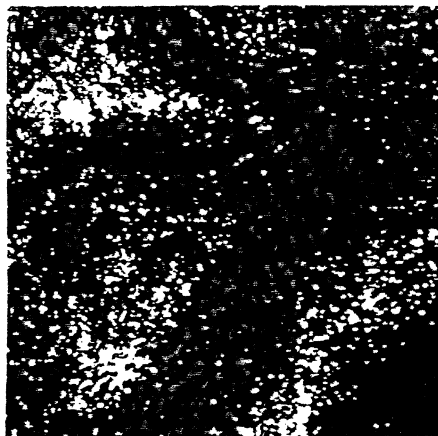
C. Culturally Disturbed
Category #3



D. Culturally Disturbed
Category #4



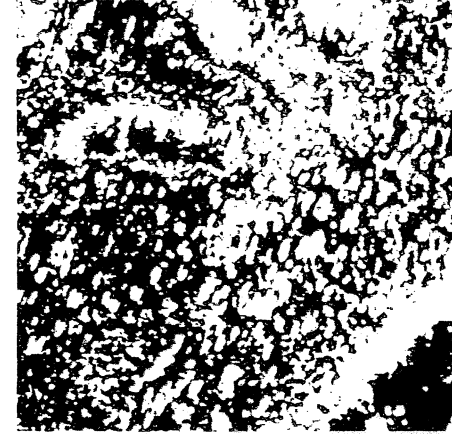
E. Cliff
Category #5



F. Bare Soil
Category #6



G. Tree Categories
Combined #7,8



H. Grass
Category #9

Figure 10: Color enhancements of individual categories.

Viewed another way, there appear to be common patterns between categories 2 and 3, and, to lesser extent, between 4 and 6. These represent three of the culturally disturbed sites and bare soil. This is an expected result considering the paucity of vegetation and the likelihood that disturbed areas in a low rainfall area become denuded. The easiest method of comparing the distributions, however, is to combine them into a single color composite (Figure 11). When this is done, the overlapping elements form new colors to highlight the unique attributes of a single category, or group of categories.

The most interesting pattern in Figure 11 is the distribution of yellow-orange spots indicated by the letters A through E. Two of these (A & B) coincide in size and location with training categories 3 and 2 in the original data set. These are reported on the Frijoles quadrangle as culturally disturbed. Sites C, D, and E are not listed as having been disturbed. Figure 11 therefore stands as an encouraging result. It leads us to an interim rejection of the null hypothesis that sites cannot be discriminated using a supervised approach. Figure 12 shows a more natural rendition of the study area. The culturally disturbed category #2 in white (Figure 10) is superimposed on a channel 4, 9, and 11 color composite in blue, green, and red, respectively.

IV. Field Verification

The results of the canonical analysis shown in Figure 11 were field verified in July 1978. The study area was traversed



Figure 11: Nine category color combination. Note the small patches of intense yellow-orange. These coincide at A and B with known culturally disturbed sites. Additional possible sites are indicated at C, D and E. Yellow-orange = culturally disturbed sites; dark blue = base soil and rock face; grey-green = trees; red = grass; brownish-red = undetermined.



Figure 12: Culturally disturbed category #2 in white superimposed on a channel 4, 9, 11 color composite in blue, green and red respectively.

to locate as many culturally disturbed sites as possible. All sites were then plotted onto 1:6,000 scale black and white aerial photographs. The resolution of the photographs was such that the sites could be precisely located. An attempt was then made to correlate those sites with the signatures, shown in yellow-orange in Figure 11, produced by canonical analysis.

The images produced by canonical analysis have not been geometrically corrected to match the scale or accuracy of the 1:24,000 quadrangle. Their interpretation, therefore, depends on using general geographic position as the best clue for matching spectral response to actual locations on the ground. We could do this relatively accurately in our study because of the small size of the overall area. Nevertheless, further refinement of the data to quantify the RMS error needs to be undertaken to correct the image geometry.

The sites located within the study area were usually marked by obsidian, chert fragments, and sherds around a small mound. In the larger and more visible sites, partially exhumed wall structures were seen. Figure 4 (p. 9) shows several sites typical of those found within the study area.

Many of the sites have little to no vegetative cover and subsequently have a high reflectivity. Areas of bare soil not associated with a culturally disturbed site and areas of bare rock also have high albedos. Thus, some of the yellow-orange areas found in the image relate to locations of exposed parent rock or bare soil. Furthermore, much of the parent rock exposure is along the ridges of

Alamo Canyon and other small drainages, as previously noted the ridges are also favored locations for disturbed sites.

From our field verification it appears that the canonical analysis was able to identify many of the favored terrain locations for disturbed sites. Several known sites occurred within the areas having a yellow-orange signature. Those sites which were known to exist but which did not show up in the image are apparently in areas having a somewhat lower reflectance.

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Airborne Infrared Scanners

Manufacturer	Model	Channels	Spatial Resolution	FOV	Temp. Resolution	Cost	Display
Bendix Aerospace Systems	LN-3	8-13 μm	2.5 mr 2.5 ft/1000 ft	$\pm 60^\circ$	0.1 $^\circ\text{C}$	Lease only	70 mm Film
	(M ² S)	10 in visible and near IR 1 at 8-14 μm	2.5 ft/1000 ft	$\pm 50^\circ$	0.5 $^\circ\text{C}$	\$180,000	Magnetic Tape
Daedalus Enterprises, Inc.	DS 1260	10 in visible and near IR 1 at 8-14 μm	2.5 ft/1000 ft	$\pm 42^\circ$	0.2 $^\circ\text{C}$	Channels: 1-\$200K 11-\$250K	Digital on Magnetic Tape
	DS 1250	10 in visible and near IR 1 at 8-14 μm	2.5 ft/1000 ft	$\pm 39^\circ$	0.2 $^\circ\text{C}$	Earlier Version Special Order Only	Analog on Magnetic Tape
AGA	750	2-5.6 μm	3.4 ft/1000 ft	20 $^\circ$ x 20 $^\circ$	0.2 $^\circ\text{C}$	\$40,000	Direct Video
	680 LW	7-12 μm	2.5 ft/1000 ft	25 $^\circ$ x 25 $^\circ$	0.2 $^\circ\text{C}$	\$62,000	Direct Video
Texas Instruments, Inc.	RS-310	3-5 μm or 8-14 μm	1 ft/1000 ft	$\pm 50^\circ$	0.2 $^\circ\text{C}$	About \$100,000	70 mm Film or Magnetic Tape (analog or digital)

Source: Aerodyne Research, Inc., Advanced Development Division, Final Report, Contract No. EX-76-C-01-2109, Report No. ARI-ADD-77-1, 12 April 1977. "Infrared Thermography Requirements Study for Energy Conservation" p. 4-27.

