Comparison of the Spectral Information Content of Landsat Thematic Mapper and SPOT for Three Different Sites in the Phoenix, Arizona Region

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ABSTRACT: Integration of data collected by different remote sensors to fully utilize complementary information has become an important component of digital image processing. Due to the large data volume, it is critical that the user merge multisensor data sets that are complementary rather than duplicative. This project dealt with the analysis and comparison of the spectral information content of four bands of the 30-m Landsat Thematic Mapper (TM) data and the three bands of the 20-m SPOT multispectral (XS) data. The correlation between the SPOT 20-m and 10-m panchromatic data were also derived.

Agricultural, urban, and geologic sites in the Phoenix, Arizona region were used in the analyses. The correlation matrix of all data sets was used along with the results of principal component and visual analyses. Statistically, the TM data for the agricultural and urban sites contained more spectral information than the SPOT XS data. The Landsat TM images for the agricultural and geologic sites clearly contained more information than the SPOT XS image. The Landsat TM band 5 revealed field/soil differences not seen in the other spectral bands. The higher resolution SPOT 10-m panchromatic data were used to "sharpen" the TM images with SPOT's finer resolution element.

INTRODUCTION

In recent years, there has been a large increase in the amount of remotely sensed image data that are available to users for analysis and mapping purposes. Data are available from imaging systems such as the Landsat multi-spectral scanner (MSS) and Thematic Mapper (TM), Seasat and Shuttle Imaging Radar (SIR-A and B), Advanced Very High Resolution Radiometer (AVHRR), and most recently from the System Probatoire d'Observation de la Terre (SPOT). Integrating and merging digital image data collected by different remote sensors has become an important component of digital image processing to fully utilize complementary information. By digitally merging multisensor digital images the user can take advantage of the unique characteristics of each particular data set.

Examples of data sets collected by different sensors at different times that have been digitally merged for processing and analysis include Landsat MSS and radar image data from Seasat and SIR-A (Daily *et al.*, 1978; Daily *et al.*, 1979; Chavez *et al.*, 1983); Landsat MSS and return beam vidicon (RBV) data (Lauer and Todd, 1981); Landsat MSS and Heat Capacity Mapping Mission (HCMM) data (Schowengerdt, 1980); Landsat TM and digitized NHAP photographic data (Chavez, 1986); Landsat TM and SPOT panchromatic data (Welch and Ehlers, 1987). Often, the spatial resolution of the data is such that the large volume of data can quickly make the handling, manipulating, and processing of a combined data set very difficult. Because of this, it becomes critical that the user merge and work with data sets that complement, and not duplicate, each other's information content. It is to the user's advantage to work with as few components or "bands" as possible because it reduces the volume of data that must be processed and analyzed.

Two widely used data sets are the Landsat TM and SPOT images. The Landsat TM data have a spatial resolution of 30-m with six reflective spectral bands, excluding the thermal band; and the SPOT multispectral (XS) data have a 20-m resolution with three spectral bands, plus a 10-m panchromatic band (see Table 1). Earlier projects have compared Landsat TM with SPOT Simulator and MSS data. They concluded that due to TM bands 1, 5, and 7 the Landsat data had spectral information not contained in the multispectral SPOT Simulator or Landsat MSS data (Chavez and Berlin, 1984; Crist, 1984; Crist and Cicone, 1984). The primary objective of this project was to compare the spectral information content of digitally registered Landsat TM and SPOT data for three very different test sites in the Phoenix, Arizona region. As with Crist and Cicone (1984) the term "information" is used in an informal rather than a formal sense. As stated by them, "new information indicates the apparent presence of previously unavailable clues or insights into the characteristics of the scene being viewed."

TABLE 1. SPECTRAL CHARACTERISTICS OF THE LANDSAT-5 TM AND SPOT IMAGING SYSTEMS.

BAND	WAVELENGTH (μm)	BAND	WAVELENGTH (μm)
TM 1	0.45 to 0.52		
2*	0.52 to 0.62	SPOT XS1	0.50 to 0.59
3	0.63 to 0.69	XS2	0.61 to 0.68
4	0.76 to 0.90	XS3	0.79 to 0.89
5	1.55 to 1.75		
7*	2.08 to 2.35		
		PAN	0.51 to 0.73

*Bands not used in this comparative analysis.

Discussed are the results of comparing the Landsat TM bands 1, 3, 4, and 5 with the SPOT XS bands 1, 2, and 3 for agricultural, urban, and geologic sites. The analysis and comparisons were made statistically (using the correlation matrix of all the data involved and evaluating the principal components results), as well as qualitative (using visual comparisons). The SPOT 10-m panchromatic band was also used to "sharpen" the detail within the TM images, realizing that its 10-m resolution has spatial details not present in the Landsat TM data. The Landsat data included only TM bands 1, 3, 4, and 5; TM bands 2 and 7 were not available. However, from previous work it has been established that TM band 2 is highly correlated with TM bands 1 and 3, while TM band 7 is highly correlated with TM band 5; there-

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fore, the results, perhaps not identical, should be similar to using all six bands (Chavez *et al.*, 1984).

DATA PREPARATION

For the three test sites the 30-m Landsat TM, 20-m SPOT XS, and 10-m SPOT panchromatic data were all digitally registered to each other. The evaluation was done using this registered data set at a resampled 10-m pixel size. The combining of data from different sensors, or sources, involves two major and distinct steps. The first deals with the geometric registration of the data. The second step involves the merging of the data, or information, for analysis (Chavez, 1986).

The first step was done by the EROS Data Center (EDC) in Sioux Falls, South Dakota. Standard type image-to-image registration procedures were used (June Thormodsgard, personal communication). The SPOT panchromatic image was used as the master and the Landsat TM image was the slave. Over 100 image control points were used to register the slave to the master. The final results were generated using a second-order polynomial fit with cubic convolution resampling. The RMS error of flat areas was under 10 metres (June Thormodsgard, personal communication). Due to the slight viewing angle and spatial resolution differences, there are still registration problems on steep slopes in the mountain areas.

Once the data sets have been geometrically registered to each other, the second step involves the actual merging or "combining" of the data. The method used to combine the digital data can influence the type of information seen in the resultant product. Methods that can be used to combine the information from two registered data sets include pixel-by-pixel arithmetic (add, subtract, or ratio—Chavez, 1986), principal component analysis, or hue-intensity-saturation transformation (Hayden *et al.*, 1982; Thormodsgard and Feuguay, 1987).

When a higher resolution image is merged with a set of lower resolution images, usually an important objective is to preserve as much of the high spatial resolution as possible. To accomplish this, the authors prefer to use the simple pixel addition method because it adds the higher resolution image equally to all the lower resolution components (e.g., add SPOT panchromatic to each of the TM bands). However, due to the fact that some of the spectral windows covered by the two sensors can be different, Landsat TM and SPOT panchromatic in this case, this method, as well as others, can distort the spectral characteristics or color balance of the various cover types in the image. This is especially true with images that have a substantial amount of vegetation and use data recorded in the near-infrared part of the spectrum.

This problem can be minimized by applying a small (11 by 11 to 25 by 25) high pass spatial filter to the higher resolution image, SPOT panchromatic in this case, before it is digitally merged with each of the lower resolution images. This will enhance the high frequency/spatial information but, more important, it will suppress the low frequency/spectral information in the higher resolution image. This allows the higher resolution image to be added equally to each of the lower resolution images using the simple pixel addition method without distorting the spectral balance. With pixel addition all the resultant components have the same spatial resolution, which may not be the case if different weighted values are used to mix the two data sets together. The TM data used in this project were collected on 5 April 1986 by Landsat-5 and the SPOT data were collected on 3 April 1986.

TABLE 2. CORRELATION MATRIX OF THE AGRICULTURAL SITE NEAR PHOENIX, ARIZONA USING THE ORIGINAL LANDSAT TM, SPOT XS, AND SPOT PANCHROMATIC DATA.

PAN	XS1 0.950		XS2 0.960		XS3 −0.257		
	XS1	XS2	XS3	TM1	TM3	TM4	TM5
XS1	1.000						
XS2	0.955	1.000					
XS3	−0.200	−0.326	1.000				
TM1	0.913	0.857	−0.249	1.000			
TM3	0.899	0.935	−0.344	0.925	1.000		
TM4	−0.234	−0.362	0.933	−0.225	−0.342	1.000	
TM5	0.699	0.751	−0.127	0.713	0.838	−0.129	1.000

ANALYSIS AND RESULTS

AGRICULTURAL SITE

The agricultural site lies approximately 10 km southwest of Phoenix in the Salt River Valley. The winter wheat crop was nearing maturity and was just about ready for harvesting. The other major mature crop was alfalfa. Most of the vegetation/crops seen in this area are one of these two types. Cotton, although a major crop in this area, is planted in April so there was no visible biomass. Summer fruits and vegetables, such as melons, also had just been planted or the fields were being prepared for planting. There are also a few isolated citrus groves in the area. Plates 1a and 1b show the results of two color composites generated for this site. Plate 1a shows the color composite made from combining Landsat TM bands 1, 3, and 4 with the 10-m SPOT panchromatic band. The colors seen in this image are very similar to those generated with the similar bands of either the Landsat MSS or SPOT XS data (i.e., vegetation is depicted in red). For visual display, a composite made from Landsat TM bands 1, 3, and 4 was used instead of a composite of the SPOT XS bands. This was done so that the spatial resolution difference would not influence the information content seen in the resulting products. The statistical analysis showed that TM bands 1, 3, and 4 are highly correlated to SPOT XS bands 1, 2, and 3, respectively (Table 2); because the objective is to compare the spectral and not spatial information, the TM composite was used. Plate 1b shows the color composite made by combining Landsat TM bands 1, 4, and 5 with the 10-m SPOT panchromatic band. The vegetation is green in this combination because the near infrared band (TM 4) was used as the green component in the color composite.

By visually comparing these two color-composite images, it is observed that there are locations in the images where differences in hues/colors can be seen. More unique hues can be identified in the composite that uses TM band 5 than on the MSS and SPOT equivalent products. Because the number of hues cannot be increased with simple linear stretching, it can be assumed that the more hues imply more spectral variability (Goetz *et al.*, 1985). For example, notice the red hues in some of the fields in Plate 1b. We have observed a similar hue in two other areas. One of the areas was inside a cattle feed yard northeast of Phoenix in this same data set. The inside of the feed yard, covered with cattle manure, was bright red in this same color composite. The second area with similar hues was encountered during an earlier project using other Landsat TM data with the same band combination. It was in the mountains just west of Las Vegas, Nevada.

Stoner and Baumgardner (1980) studied the spectral response of soils with three different concentrations of organic matter: less than 3 percent, 3 to 5 percent, and 5 to 10 percent. The differences in reflectance curves of these three concentrations of organic matter is larger in the visible and near-infrared regions than in the middle-infrared wavelengths (Stoner and Baumgardner, 1980, pp. 54-55). Also, the reflectance in the visible and near-infrared is less than in the middle-infrared region. This indicates that the visible and near-infrared (TM bands 1

PLATE 1a. Color composite of TM bands 1, 3, and 4 merged with the SPOT panchromatic band for the agricultural site. Interstate 10 is at the top and the Salt River is at the bottom. Several locations have been labeled with letters A and B for comparison with the image shown in Plate 1b below. The areas to compare are those to the right of the letters. The image covers approximately a 15 by 10 km area and north is to the top. Copyright SPOT data CNES; TM data reproduced with permission of EOSAT.

PLATE 1b. Color composite of TM bands 1, 4, and 5 merged with the SPOT panchromatic band for the agricultural site. The vegetation is green because TM band 4 was used as the green component. The print is labeled for comparison with Plate 1a. The three A's are showing some of the red hues in the fields. The three B's are showing some of the hues that are different or unique compared to their hues in Plate 1a. Copyright SPOT data CNES; TM data reproduced with permission of EOSAT.

and 4) will be darker than will the middle-infrared (TM band 5) with the higher concentrations of organic matter. The average reflectance spectra (bidirectional reflectance factor—BRF) for soils with these three levels of organic matter is shown by Stoner and Baumgardner (1980) to have approximately the following percentage values: TM band 1 is 5, 4, and 4 percent; TM band 4 is 15, 10, and 8 percent; and TM band 5 is 21, 18, and 15 percent, respectively.

These values show that, for high concentrations of organic matter, the BRF in TM band 5 is almost four times greater than TM band 1 and almost twice that of TM band 4. This combination of TM bands used in a color composite as blue, green, and red, respectively, as we did would generate a red hue. Notice that the absolute reflectance of the high concentration of organic matter is less than in the lower concentrations. However, using ratios to look at the relative amplitude, the ratio of the middle-infrared (TM band 5) to the visible (TM band 1) and near-infrared (TM band 4) is higher. These ratios show that with the given relationship between these bands, and if used as blue, green, and red in a color composite will generate orange or pink colors in the composite.

Most of the fields in the agricultural site belong to large commercial farmers whose general practice is to use a nitrogen-based fertilizer. Fields that have recently been fertilized would have a higher than normal amount of organic type matter. The occurrence of this similar hue inside the cattle feed yard and in the agricultural site suggests that one possible cause could be the high concentration of organic matter in the soils. There are different levels of red and pink hues that can be seen in the various fields and may be related to the amount of organic matter present (cattle feed yard was bright red and some fields in the Phoenix area are red to light pink due to the brightness variations in TM band 5).

Table 2 shows the correlation matrix for the SPOT XS versus the SPOT panchromatic, the SPOT XS versus the Landsat TM, SPOT XS versus SPOT XS, and Landsat TM versus Landsat TM data. Bands XS1 and XS2 of the SPOT 20-m data are highly correlated to the SPOT 10-m panchromatic band (0.950 and 0.960, respectively). These two XS bands are also highly correlated with each other (0.955). The correlation of these two visible bands with the near-infrared bands (XS3) is low and negative. This is attributable to the amount of vegetation in the area. The same pattern is seen in the Landsat TM bands with each other. For example, TM bands 1 and 3 have a correlation of 0.925 and their correlations to TM band 4 are −0.225 and −0.342, respectively. The correlation of Landsat TM band 5 with the TM band 4 (near-infrared band) is very low and its correlation with the bands in the visible portion of the spectrum is intermediate.

The principal component results of the original Landsat TM bands 1, 3, 4, and 5 were compared with the principal component results of the original SPOT XS1, XS2, and XS3 bands. The percent of variance that was mapped to each component is shown in Table 5 for the three sites. This table shows that, for the agricultural site, 99.0 percent of the total variance in the three SPOT bands was mapped to the first two components. This compared to 92.6 percent of the total variance being mapped to the first two components in the Landsat TM results. The individual principal components of the Landsat TM and SPOT data are shown in Figure 1. The data incorporate a linear stretch to increase the contrast in each of the images for visual display. It is easy to see the high degree of correlation between the first principal component of the TM and SPOT data (Figures 1a and 1e). Some of the differences that exist between the TM and SPOT data can be seen in the lower components (see Figures 1b, 1c, 1d, 1f, and 1g).

The statistics shown in Table 2, and supported by Table 5, show that the SPOT XS data for this site were approximately two-dimensional and the Landsat TM data were close to three-dimensional (dimensions are used in the statistical sense and relate to the number of variables or components per pixel). Similar results were derived by Crist and Cicone (1984) with simulated Landsat MSS and TM data. They used the Tasseled Cap Transformation to look at the information contents of field data converted to equivalent MSS and TM digital values. They concluded that the brightness and greenness components of the two data sets were very similar and that the new information was mostly in the third component of the TM Tasseled Cap Transformation. In our study we have used the values of the correlation coefficients (Table 2) and principal component analysis results (Table 5) to reach similar conclusions for our data sets. Table 2 shows the amount of correlation between the visible, near-infrared, and mid-infrared (TM band 5) bands. Notice the low to moderate correlation of TM band 5 with the visible and near-infrared bands; as with Crist's and Cicone's two-dimensional plots of the Tasseled Cap Transformation, the amount of correlation and the percent of variance mapped beyond the second principal component implies that there is new information in the third-dimension in the Landsat TM data compared to the SPOT XS data.

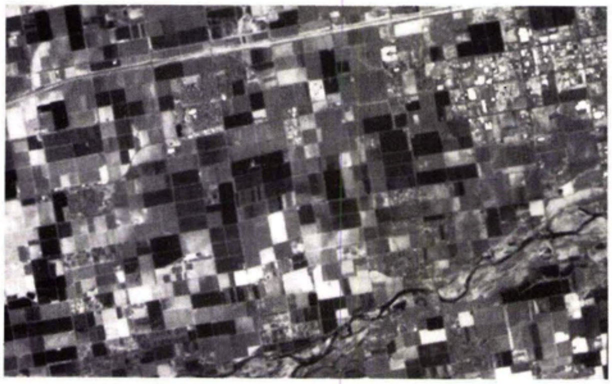
The correlations between the Landsat TM and SPOT bands that cover approximately the same spectral bands are high. For example, Landsat TM band 3 and SPOT band XS2 (the red portion of the spectrum) have a correlation of 0.935; the near-infrared bands (TM band 4 and SPOT XS3) have a correlation of 0.933.

Urban Site

The urban site lies inside the city limits of Phoenix and includes high- and low-density residential areas, as well as commercial zones. For this particular site, it was difficult to see any visual differences in the spectral information content of TM bands 1, 3, 4, (Landsat MSS and SPOT XS equivalent bands) and TM bands 1, 4, 5 color composites. There are some subtle differences in detail that can be seen inside parks and golf courses in the TM band 1, 4, and 5 combination. Other than this, the visual information content of both products appears to be equal. The two TM color composite combinations used here included the 10-m SPOT panchromatic band to improve the spatial resolution.

Table 3 shows the correlation matrix for the SPOT XS versus the SPOT panchromatic, the SPOT XS versus the Landsat TM, SPOT XS versus SPOT XS, and Landsat TM versus Landsat TM data. Bands XS1 and XS2 of the SPOT 20-m data are moderately to highly correlated with the SPOT 10-m panchromatic band. These correlations are not as high as those for the agricultural data. These two XS bands are also highly correlated with each other in a manner similar to the agricultural data set. As with the agricultural data, the correlation of these two visible bands with the near-infrared band (XS3) is low, but not negative. Even in the urban area, enough vegetation is present that it has an influence in the near-infrared bands. The same correlation pattern is seen in the Landsat TM bands. For example, TM bands 1 and 3 have a correlation of 0.916 and their correlations to TM band 4 are 0.289 and 0.314, respectively. The correlation of Landsat TM band 5 with the near-infrared is not as low as it was for the agricultural data, while its correlation with the bands in the visible portion of the spectrum are lower than they were for the agricultural data.

The principal component results of the original Landsat TM bands 1, 3, 4, and 5 were compared with the principal component results of the original SPOT XS1, XS2, and XS3 bands. The percent of variance that was mapped to each component is shown in Table 5. The table indicates that, in the urban site, 97.8 percent of the total variance in the three SPOT bands was mapped to the first two components. This compared to 89.0 percent of the total variance being mapped to the first two components in the



(a)

(e)

(b)

(f)

(c)

(g)

(d)

FIG. 1. Principal component image results of the original Landsat TM bands 1, 3, 4, and 5 ((a) to (d)) and original SPOT bands XS1, XS2, and XS3 ((e) to (g)) for the agricultural site. The correlation of the first component of both data sets ((a) and (e)) is 0.859. The correlation between the second components ((b) and (f)) is 0.828; some of the information unique to the TM data is starting to show up (see all the locations just to the right of the **a**). The correlation between the third components ((c) and (g)) is −0.458; the SPOT third component is more correlated to the TM fourth component (0.625). Most of the bright areas in the TM third principal component relate to the red hues seen in the fields in Plate 1b. Both the TM third and fourth components are also showing some of the differences in information contents between the two data sets (look to the right of the **a**). Copyright SPOT data CNES; TM data reproduced with permission of EOSAT.

TABLE 3. CORRELATION MATRIX OF THE URBAN SITE NEAR PHOENIX, ARIZONA, USING THE ORIGINAL LANDSAT TM, SPOT XS, AND SPOT PANCHROMATIC DATA.

PAN	XS1 0.795		XS2 0.756		XS3 0.304		
	XS1	XS2	XS3	TM1	TM3	TM4	TM5
XS1	1.000						
XS2	0.937	1.000					
XS3	0.404	0.326	1.000				
TM1	0.846	0.781	0.251	1.000			
TM3	0.808	0.826	0.253	0.916	1.000		
TM4	0.329	0.261	0.922	0.289	0.314	1.000	
TM5	0.431	0.489	0.499	0.435	0.637	0.604	1.000

Landsat TM results. The individual principal components of the Landsat TM and SPOT XS data are shown in Figure 2. The high degree of correlation between the first components of the TM and SPOT data can easily be seen (Figures 2a and 2e). The lower components show some of the differences and similarities between the two data sets (Figures 2b, 2c, 2d, 2f, and 2g).

The statistics shown in Table 3, and supported by Table 5, show that the SPOT XS data for this site are approximately two-dimensional, similar to the data from the agricultural site. The Landsat TM data were also similar to the agricultural site data, that is, approximately three-dimensional.

The correlations between the urban Landsat TM and SPOT XS bands that cover approximately the same spectral regions are not as high as they were for the agricultural data; however, they still remain moderately to highly correlated. For example, the red bands (TM band 3 and SPOT and XS2) have a correlation of 0.826; the near-infrared bands (TM band 4 and SPOT XS3) have a correlation of 0.922.

GEOLOGIC SITE

The geologic site lies approximately 20-km northeast of Phoenix and includes the new Fountain Hills development. It is mostly a semi-desert mountainous environment with sparse vegetation growing at the time of imaging due to winter and spring rains. The McDowell Mountains represent the main topographic feature in the area. The Central Arizona Project canal is in the lower left of the image. Lithologic units in the area include Precambrian granite, schist, and granite gneiss; Cretaceous/Tertiary sedimentary rocks; and Tertiary/Quaternary volcanic rocks. Plates 2a and 2b are color composites generated for this site. Plate 2a shows the color composite made from combining Landsat TM bands 1, 3, and 4. The colors seen in this product are very similar to those that are generated with either the Landsat MSS or SPOT multispectral data. Notice that the only place where there is detectable vegetation cover is the park and golf course area within the Fountain Hills complex.

Plate 2b shows the color composite made from combining Landsat TM bands 1, 4, and 5. The vegetation is green in this combination because the near-infrared band (TM 4) was used as the green component in the composite. By visually comparing these two products, it can be seen that there are many locations in the images where differences exist. The composite that uses TM band 5 has more distinct hues than do the similar bands of either the Landsat MSS or SPOT data. For example, the reds seen around the Verde Mountain region (Area A in Plate 2) are in a volcanic environment and are similar to those seen by us in other volcanic areas where hematitic alteration was present (Chavez *et al.*, 1984; Davis *et al.*, 1987). Other areas near the McDowell Mountains also have this same hue. In the mountains there are also several other hues that can be seen in the composite with TM band 5 (plate 2b) but are not seen in the similar bands of either the Landsat MSS or SPOT equivalent composite (area B in plate 2a). Another hue seen much better in the composite with TM band 5 is the gray triangular shaped feature seen on the east side of Fountain Hills (area C in plate 2). On the non-TM band 5 composite, this feature is difficult to detect. The differences in the amount of hues present between these two products are very similar to those seen by us in several other sites (for example, Northern Arizona, Death Valley, and Nevada (Chavez *et al.*, 1984; Davis *et al.*, 1987)).

The statistics for the geologic site were somewhat confusing based upon the visual results and the statistics of the agricultural and urban sites. Statistically, the uniqueness of the information added by TM band 5 was not as strong as expected for this site. In our previous work, TM band 5 had a medium to low correlation to the visible and near-infrared bands in desert type environments. For this site, the correlations are medium to high (Table 4). However, the patterns seen in the visual analysis are similar to those seen in other projects. They have shown a lower TM band 5 correlation with the visible and near-infrared bands for vegetated areas as compared to the desert areas (Chavez *et al.*, 1984). The results seen for the three sites used in this project also showed this except that in the geologic site the TM band 5 correlations with the other TM bands are higher than expected; this was a surprise because the visual evaluation identified so many hue differences seen only in the composite with TM band 5.

Table 4 shows the correlation matrix for the SPOT XS versus the SPOT panchromatic, the SPOT XS versus the Landsat TM, SPOT XS versus SPOT XS, and Landsat TM versus Landsat TM data. Bands XS1 and XS2 of the SPOT 20-m data are highly correlated to the SPOT 10-m panchromatic band. For this site band XS3 also has a substantial correlation to the panchromatic band (0.789). The much higher correlation between XS3 and the panchromatic data seen for this site, compared to the agricultural and urban sites, may be due to the lack of vegetation. The correlations between the three XS SPOT bands are also high.

As with the other two sites, principal component results of the original Landsat TM bands 1, 3, 4, and 5 were compared with the principal component results of the original SPOT XS1, XS2, and XS3 bands. The percent of variance that was mapped to each component is shown in Table 5. This table shows that, for the geologic site, 98.6 percent of the total variance in the three SPOT bands was mapped to the first two components. This compared to 96.5 percent of the total variance being mapped to the first two components in the Landsat TM results. Statistically, the results showed that the SPOT data for this site were approximately one-dimensional and the Landsat TM only slightly higher (see Tables 4 and 5). The reduction by one dimension, as compared to the other sites, may be due to the lack of vegetation, which reduced the contribution of the near-infrared bands in both systems. The individual contrast stretched principal components of the Landsat TM and SPOT data are shown in Figure 3. As with the other two sites, it is easy to see the high amount of correlation between the first principal component of the TM and SPOT data (Figures 3a and 3e). Some of the differences that are easily seen in the visual comparison can be seen in the lower components (see Figures 3b, 3c, 3d, 3f, and 3g).

As in the other two sites, the correlation between the Landsat TM and SPOT bands that cover approximately the same spectral windows is also high. For example, Landsat TM band 3 and SPOT and XS2 (the red portion of the spectrum) have a correlation of 0.910; the near-infrared bands (TM band 4 and SPOT XS3) have a correlation of 0.890. The correlation of Landsat TM band 5 with the near-infrared band is moderate to high and its correlation with the bands in the visible part of the spectrum is moderate to slightly high.

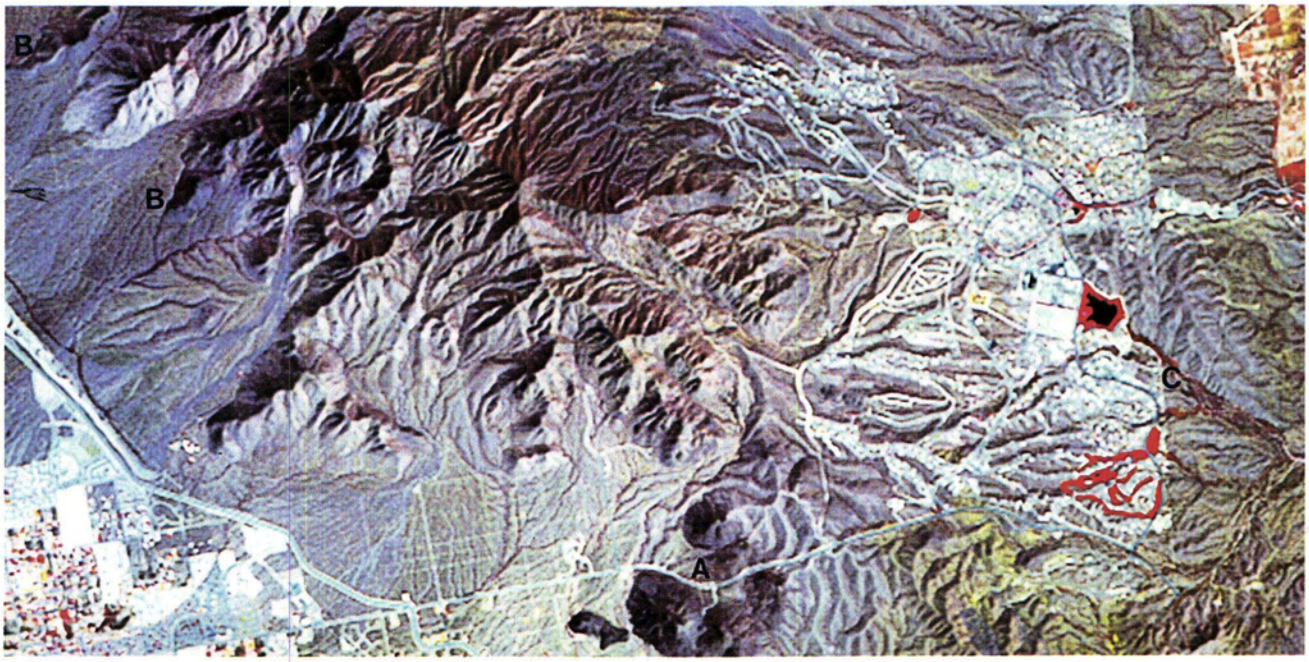


PLATE 2a. Color composite of TM bands 1, 3, and 4 for the geologic site. The McDowell Mountains and the new development of Fountain Hills are the main features in the image with the Central Arizona Project canal going diagonally at the lower left. The highway to the Fountain Hills area can also be seen at the bottom of the image. The image covers approximately a 10 by 6 km area and north is to the top. Several locations have been labeled for comparison with the image shown in Plate 2b below. The areas to compare are just to the right of the letters used as labels. Used with permission of EOSAT.

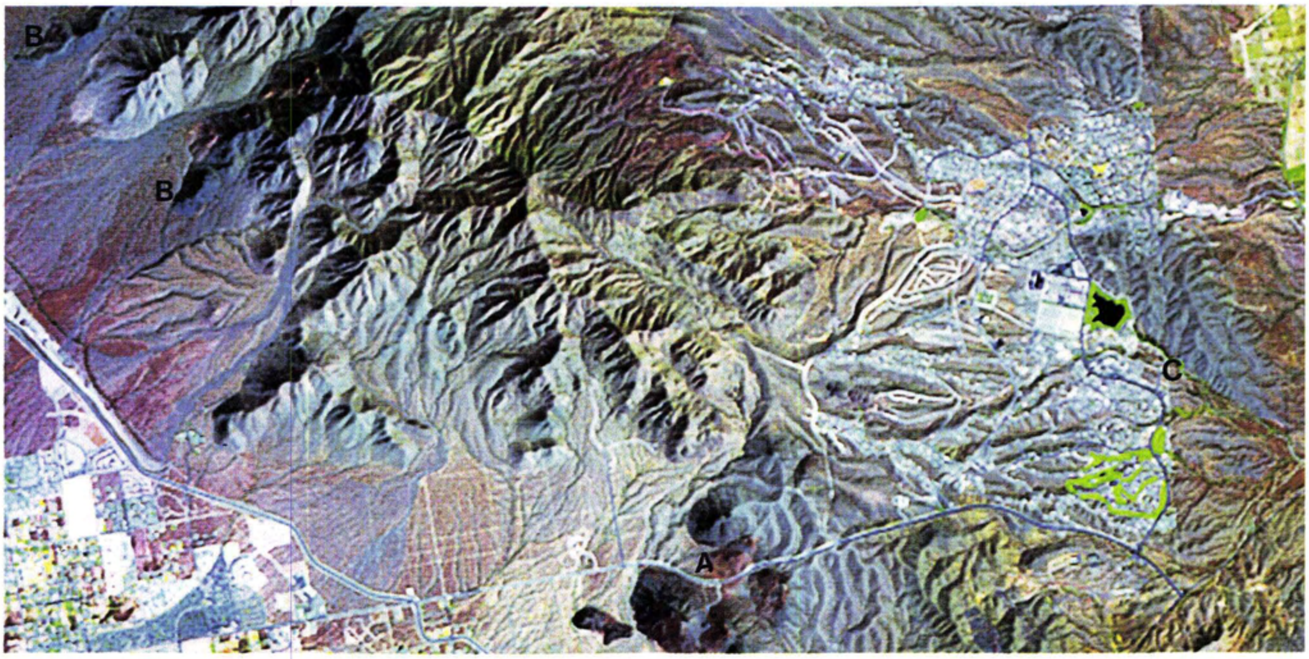
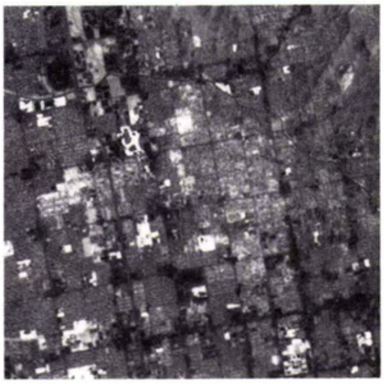


PLATE 2b. Color composite of TM bands 1, 4, and 5 for the geologic site. This print is labeled in the same locations as Plate 2a for comparison. Letter A, below the center of the image, is in the Verde Mountain area and indicates some of the red hues in the volcanic area (possibly caused by hematite as in other volcanic areas); letter B, two locations in the upper left section of the image, show some of the color difference seen within the McDowell Mountains; letter C is showing the differences in detectability of the triangular shaped unit just to the right of the Fountain Hills area. Used with permission of EOSAT.


(a)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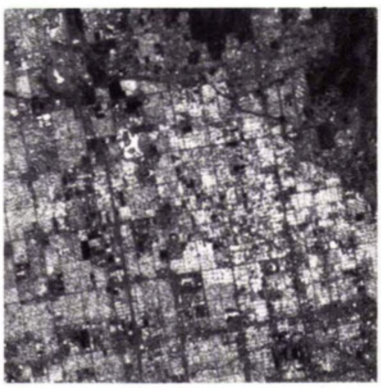
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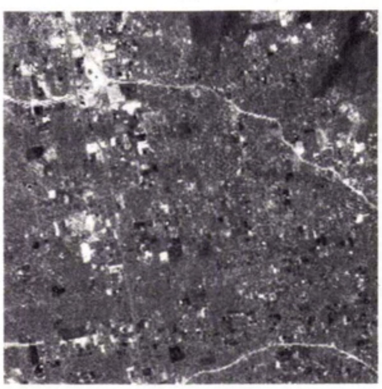
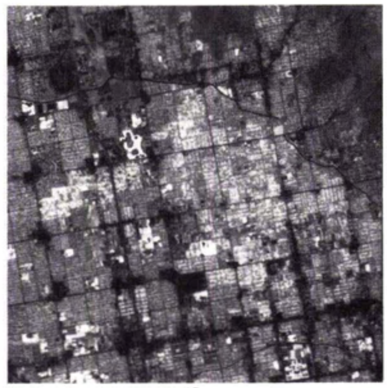

(d)


(e)


(f)

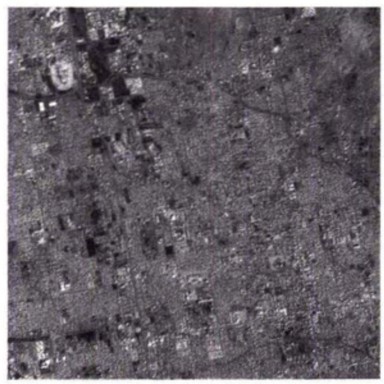
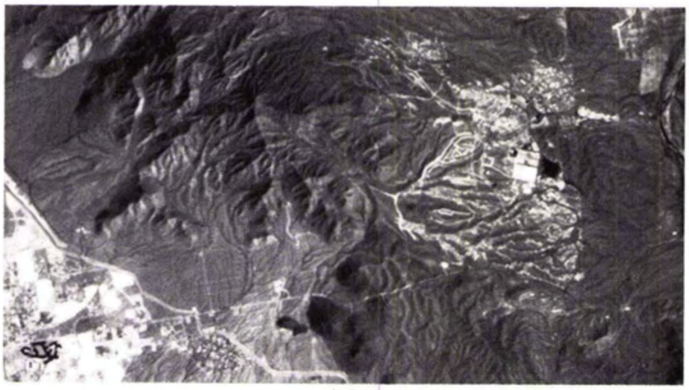
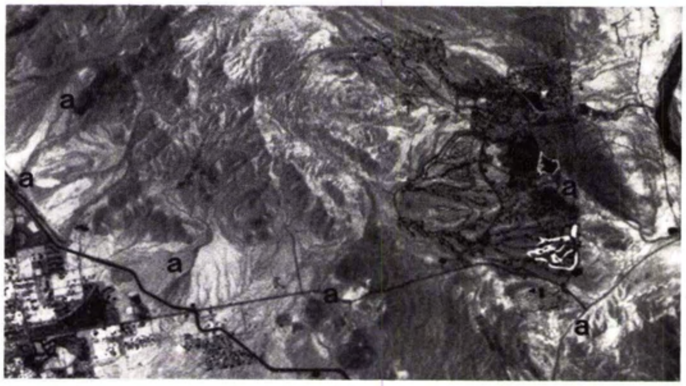

(g)

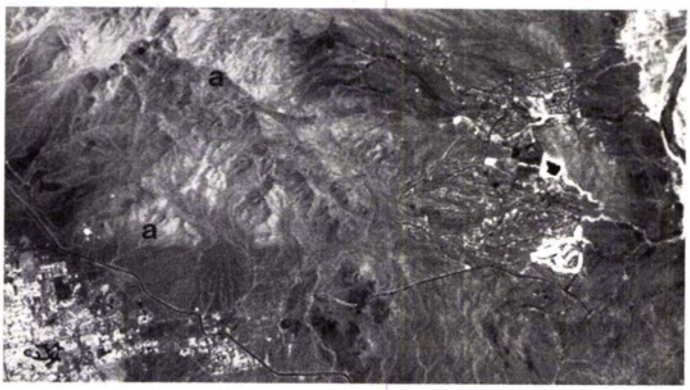
FIG. 2. Principal component image results for the Landsat TM bands 1, 3, 4, and 5 ((a) to (d)) and SPOT bands XS1, XS2, and XS3 ((e) to (g)) for the urban site. The correlation of the first component of both data sets ((a) and (e)) is 0.805. The correlation between the second components ((b) and (f)) is 0.751. The correlation between the third components ((c) and (g)) is 0.340; the SPOT third component is more correlated to the TM fourth component (−0.427). A few differences can be seen but visually the two data sets are very similar. A pattern within the residential areas seems to be present in component number 3 of the TM data but is difficult to determine if it is unique only to the TM data set. The image covers approximately a 5- by 5-km area and north is to the top. Copyright SPOT data CNES; TM data reproduced with permission of EOSAT.



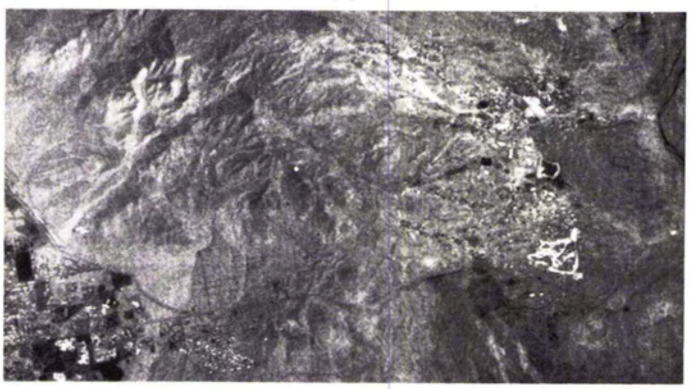
(a)



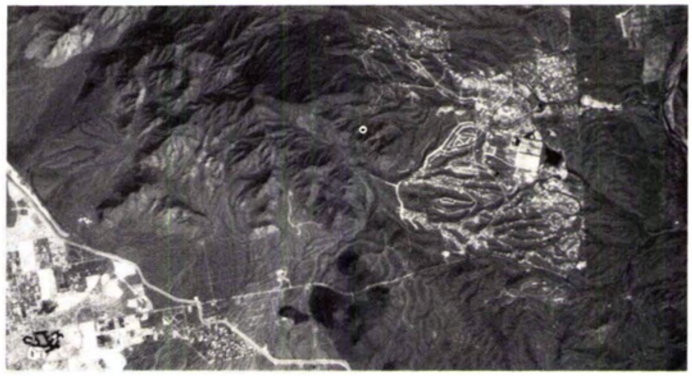
(b)



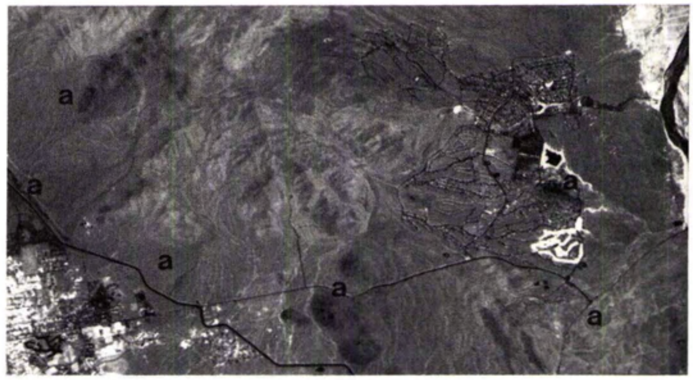
(c)



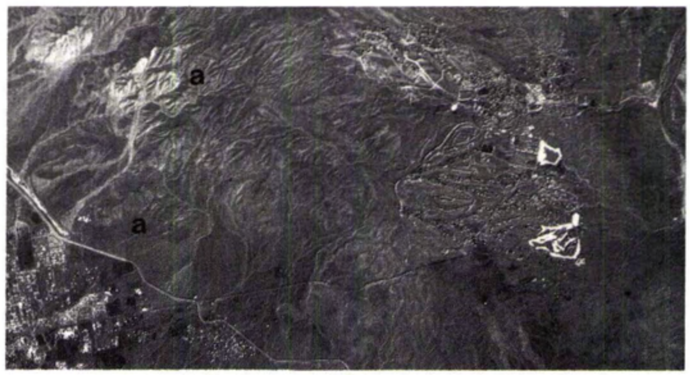
(d)



(e)



(f)



(g)

FIG. 3. Principal component image results for the Landsat TM bands 1, 3, 4, and 5 ((a) to (d)) and SPOT bands XS1, XS2, and XS3 ((e) to (g)) for the geologic site. The correlation of the first component of both data sets ((a) and (e)) is 0.680. The correlation between the second components ((b) and (f)) is 0.350; some of the information unique to the TM data is starting to show up (see all locations just to the right of the **a**). The correlation between the third components ((e) and (g)) is 0.135; the SPOT third component is more correlated to the TM fourth component (0.423). The TM lower components show some of the differences in information content between the two data sets (to the right of the **a**). Copyright SPOT data CNES; TM data reproduced with permission of EOSAT.

TABLE 4. CORRELATION MATRIX OF THE GEOLOGIC SITE NEAR PHOENIX, ARIZONA USING THE ORIGINAL LANDSAT TM, SPOT XS, AND SPOT PANCHROMATIC DATA.

PAN	XS1 0.885		XS2 0.931		XS3 0.789		
	XS1	XS2	XS3	TM1	TM3	TM4	TM5
XS1	1.000						
XS2	0.958	1.000					
XS3	0.816	0.844	1.000				
TM1	0.897	0.875	0.727	1.000			
TM3	0.876	0.910	0.784	0.950	1.000		
TM4	0.711	0.734	0.890	0.783	0.845	1.000	
TM5	0.681	0.740	0.732	0.753	0.860	0.841	1.000

TABLE 5. PRINCIPAL COMPONENTS PERCENT OF VARIANCE RESULTS FOR THE ORIGINAL LANDSAT TM AND SPOT XS DATA FOR THE THREE SITES USED IN THIS PROJECT.

	PC1	PC2	PC3	PC4
I. SPOT, XS1, XS2, and XS3				
AGRICULTURAL	67.0	32.0	1.0	
URBAN	70.5	27.3	2.2	
GEOLOGIC	94.2	4.4	1.4	
II. LANDSAT TM 1, 3, 4, and 5				
AGRICULTURAL	70.4	22.2	6.5	0.9
URBAN	64.1	24.9	9.8	1.2
GEOLOGIC	89.2	7.3	2.8	0.7

SUMMARY

The results of the analysis show that the original Landsat TM data using bands 1, 3, 4, and 5 have more spectral information than does the original SPOT XS data for these particular sites. For the agricultural and geologic sites, some of the new information is easily visible in the color composites. Visually, the urban site had very similar information content for both data sets; however, the TM data did not correlate to the SPOT XS data as much as at the other sites, and part of this may be due to the slight spatial resolution difference which has a larger effect in the urban environment. Also, as might be expected, the extent of vegetative cover seems to affect the level of spectral information and the degree of correlation between the spectral bands of both sensor systems. For test sites with vegetation the data were two- and three-dimensional for the SPOT XS and Landsat TM, respectively. In the geologic area where substantial vegetation was not present, the SPOT XS and Landsat TM data were approximately one- and two-dimensional, respectively.

For the agricultural site, TM band 5 added new information; for example, in locations that showed up as pink and red hues in our particular color composite. These hues were seen in both a cattle feed yard and fallow fields and might be related to the amount of organic matter present in the soils.

The differences in percent mapped to the first two principal components of SPOT XS versus Landsat TM for the three sites were 6.4 percent for the agricultural site, 8.8 percent for the urban site, and 2.1 percent for the geologic site. The larger percent of the total variance going into the first two components for the geologic site as compared to the agricultural and urban sites might be caused by the lack of vegetation, but it is not yet clear why the visual results of the color composites and the statistics for the geologic site were different. The results for these three sites imply that the SPOT XS data, for the most part, duplicate the spectral information contained in the Landsat TM data, while the Landsat TM data have spectral information not contained in the SPOT XS data.

REFERENCES

Chavez, P. S., Jr., 1986. Digital mapping of Landsat TM and digitized NHAP data for 1:24,000-scale image mapping; *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 10, pp. 1637–1646.

Chavez, P. S., Jr., and G. L. Berlin, 1984. Digital processing of SPOT Simulator and Landsat TM Data for the SP Mountain Region, Arizona, *Proceedings, SPOT Simulator Symposium*, Scottsdale, Arizona, pp. 56–66.

Chavez, P. S., Jr., G. L. Berlin, and L. B. Sowers, 1982. Statistical method for selecting Landsat MSS ratios; *Applied Photographic Engineering*, Vol. 1, pp. 23–30.

Chavez, P. S., Jr., G. L. Berlin, and M. A. Tarabzouni, 1983. Discriminating lithologies and surficial deposits in the Al Hisma Plateau region of Saudi Arabia with digitally combined Landsat MSS and SIR-A Images; *Proceedings, National Conference on Resources Management Applications, Energy and Environment*, Vol. 4, San Francisco, California, pp. 22–34.

Chavez, P. S., Jr., S. C. Guptill, J. Bowell, 1984. Image processing techniques for Thematic Mapper Data; *Proceedings, 50th Annual ASP-ACSM Symposium*, American Society of Photogrammetry, Washington, D.C., pp. 728–743.

Crist, E. P., 1984. Comparison of coincident Landsat-4 MSS and TM data over an agricultural region; *Proceedings, 50th Annual ASP-ACSM Symposium*, American Society of Photogrammetry, Washington, D.C., pp. 508–517.

Crist, E. P, and R. C. Cicone, 1984. Comparison of the dimensionality and features of simulated Landsat-5 MSS and TM data; *Remote Sensing of Environment*, Vol. 14, pp. 235–246.

Daily, M., C. Elachi, T. Farr, W. Stromberg, S. Williams, and G. Schaber, 1978. Applications of multispectral radar and Landsat imagery to geologic mapping in Death Valley; NASA's Jet Propulsion Laboratory Publications 78–19, 47 p.

Daily, M., T. Farr, C. Elachi, and G. Schaber, 1979. Geologic interpretation from composited radar and Landsat imagery; *Photogrammetric Engineering and Remote Sensing*, Vol. 45, No. 8, pp. 1109–1116.

Davis, P. A., G. L. Berlin, and P. S. Chavez, 1987. Discrimination of altered basaltic rocks in the southwestern United States by analysis of Landsat Thematic Mapper data; *Photogrammetric Engineering and Remote Sensing*, Vol. 53, No. 1, pp. 45–55.

Goetz, A. F. H., G. Vane, J. E. Solomon, and B. N. Rock, 1985. Imaging Spectrometry for Earth Remote Sensing, *Science*, Vol. 228, No. 4704, pp. 1147–1153.

Hayden, R., G. W. Dalke, J. Henkel, and J. E. Bare, 1982. Application of the IHS color transform to the processing of multisensor data and image enhancement; *Proceedings, International Symposium on Remote Sensing of Arid and Semi-Arid Lands*, Cairo, Egypt, pp. 599–616.

Lauer, D. T., and W. J. Todd, 1981. Landcover mapping with merged Landsat RBV and MSS steroscopic images; *Proceedings, ASP Fall Technical Conference*, American Society of Photogrammetric, San Francisco, California, pp. 68–69.

Stoner, E. R., and M. D. Baumgardner, 1980. *Physicochemical Site and Bidirectional Reflectance Factor Characteristics of Uniformly Moist Soils*; LARS Information Note 111679, Laboratory for Applications of Remote Sensing, Purdue Univ., W. Layfayette, Indiana, 94 p.

Schowengerdt, R. A., 1980. Enhanced thermal mapping with Landsat and HCMM digital base; *Technical Papers, ACSM-ASP Convention, 48th Annual Meeting*, American Society of Photogrammetry, Denver, Colorado, pp. 414–422.

Thormodsgard, J. M., and J. W. Feuguay, 1987. Larger Scale Image Mapping with SPOT; *Proceedings, SPOT-1 Utilization and Assessment Results*, Paris, France, November 23–27, 1987.

Welch, R., and W. Ehlers, 1987. Merging multiresolution SPOT HRV and Landsat TM Data; *Photogrammetric Engineering Remote Sensing*, Vol. 53, No. 3, p. 301–303.

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