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E83-10412

CR-13006

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PERFORMANCE EVALUATION AND
GEOLOGIC UTILITY OF LANDSAT 4
TM AND MSS SCANNERS



(E83-10412) PERFORMANCE EVALUATION AND
GEOLOGIC UTILITY OF LANDSAT 4 TM AND MSS
SCANNERS Quarterly Report, 4 Feb. - 4 Aug.
1983 (Jet Propulsion Lab.) 21 p
HC A02/MF A01

N83-34404

Unclas
CSCL 08G G3/43 00412

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August 1983
Combined Quarterly Report for
Period February 4 - August 4, 1983



Prepared for:
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Introduction

The primary objective of the JPL LIDQA study is to evaluate Landsat 4 TM and MSS data for geologic applications. This involves a quantitative assessment of the data quality including spatial and spectral characteristics. Landsat 4 data will be acquired and analyzed over locations which have already been studied extensively using data from Landsat 1-3, the aircraft Thematic Mapper Simulator, the HCMM satellite, and field multispectral reflectance and thermal measurements.

During the first two quarters of this study, tapes for six Landsat 4 TM scenes were acquired and processing begun. Preliminary results indicate that Landsat 4 TM data will significantly increase the amount of useful geologic information available for identification and mapping of materials. Experiments utilizing artificial targets to help calibrate and evaluate atmospheric effects and the radiometric precision and spatial characteristics of the sensor systems were attempted and showed the technical feasibility of using plastic targets for such studies, although weather precluded successful TM data acquisition.

Accomplishments and Significant Results

As part of the Landsat 4 LIDQA investigation, three experiments utilizing artificial targets were conducted. Black and white target pairs, deployed once at Mountain Pass, California (August 19, 1982) and twice at Lost River, West Virginia (October 8 and 24, 1982), had the following characteristics:

- (a) Material: 6 mil TU TUF polyethylene (in 20' x 100' sheets)
- (b) Shape: square, 25 m x 25 m (Mountain Pass) and 90 m x 90 m (Lost River)
- (c) Orientation of boundary between target pair was perpendicular to the scan direction of sensor systems (NS-001 system at Mountain Pass; NS-001 and Landsat 4 TM for Lost River)
- (d) Spectral characteristics: one of high albedo, one of low albedo in the spectral intervals measured by the aircraft/satellite scanner system. Spectra were measured in the laboratory with the Beckman 5240 and in the field during scanner data acquisition with JPL's PFRS and HHRR and Gulf's Collins field spectrometer. Target temperatures were determined with the PRT-5.

Although cloud cover during both target deployments at Lost River precluded acquisition of Landsat 4 TM data, these experiments did demonstrate:

- (a) Plastic sheeting (TU TUF and not construction grade polyethylene) is an adequate, spectrally homogeneous artificial target material for investigating scanner calibration and radiometry problems.
- (b) Large (over 4 acres for Lost River) artificial targets can be rapidly deployed, spectrally characterized in the field during scanner over-passes, removed, and reused.
- (c) Artificial target-derived calibration curves for NS-001 data acquired at Mountain Pass produced reasonable image spectra for pixels containing natural material with known reflectance spectra measured in the field.
- (d) Preflight adjustment of offset and gain settings for the NS-001 sensor are possible using sample target material. Such adjustment is required to insure that the reflectance of targets deployed at a test site fall within the dynamic range of the scanner system being evaluated.

A total of six Landsat 4 TM scenes have been acquired to date. They cover the following areas:

Death Valley, California
Silver Bell, Arizona
Owl Creek Mountains, Wyoming
Goldfield, Nevada
Owens Valley, California
Las Vegas - Lake Mead, Nevada

The Death Valley and Silver Bell data have been processed and the following products generated: color enhanced composites; color ratio composites; principal component color and black and white images; and color decorrelation enhanced images. In addition, the Death Valley TM data were co-registered with Seasat/SAR and TIMS data and were used with principal component analysis. Overall, the TM data appeared to provide a significant increase in the amount of geologically useful information; however, several instrumental or processing artifacts may limit the ability of the geologist to fully use these data. (See appended papers for details of processing and analyses done.)

The Owl Creek Mountains scene has been logged, with a true color composite and a color infrared composite generated. Preliminary photointerpreta-

tion is currently being done prior to further processing. Based on preliminary qualitative examination, the data quality is excellent for geologic assessment. There is limited cloud cover and snow is found at the highest elevations only. This is a very good scene for studying the stratigraphy of sediments exposed in the interior of the basin, and the fans and pediments around the basin margin.

The valley portion of the Owens Valley, California scene is free of snow and clouds and the data appear to be of excellent quality. These data will be registered to the JPL Landsat MSS digital mosaic of California and to DMA and other digital topographic data bases. NS-001 data of the area will also be registered for comparison.

The Goldfield, Nevada scene was unusable due to the presence of clouds. They made photometric relationships unreliable even where clouds did not obscure the ground.

Papers and Presentations

Michael J. Abrams, "Landsat 4 Thematic Mapper and Thematic Mapper Simulator Data for a Porphyry Copper Deposit," submitted to Photogrammetric Engineering and Remote Sensing.

Michael Abrams, Anne Kahle, Alan Gillespie, James Conel and Harold Lang, "Geologic Utility of Landsat 4 TM Data," presented by Abrams at the Landsat 4 Scientific Characterization Early Results Symposium at Goddard Space Flight Center, February 22-24, 1983.

Anne Kahle and Michael Abrams, "Early Landsat 4 Thematic Mapper Results in the Western United States," presented by Kahle at the 4th Geosat Workshop, Remote Sensing Frontiers, at Flagstaff, Arizona, June 12-17, 1983.

Future Plans

Data processing and analysis will continue on the tapes in hand now. When the TDRSS becomes operational and new TM data is again available, we will plan another target experiment and attempt to acquire both day and night TM data.

LANDSAT-4 THEMATIC MAPPER AND THEMATIC MAPPER SIMULATOR DATA
FOR A PORPHYRY COPPER DEPOSIT

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Computer enhanced TM Simulator and Landsat-4 TM data
are compared for a porphyry copper deposit in southern Arizona

Aircraft Thematic Mapper (TM) simulator data were acquired in 1978^{*} as part of the Joint NASA/Geosat Test Case Project (Abrams et al., 1983) in anticipation of the launch of the Landsat-4 Thematic Mapper satellite. The aircraft data were extensively processed and analyzed to evaluate the potential utility of the satellite scanner for geologic mapping and detection of hydrothermal alteration zones. Recently, TM data have become available covering parts of the western U.S., including a porphyry copper deposit in Arizona studied in the Test Case Project. These new data allow a comparison to be made between the aircraft TM simulator data and the Landsat-4 TM satellite data, which possess similar spectral bands (Table 1).

The Silver Bell porphyry copper deposit is located in southern Arizona, 50 km northwest of Tucson. Copper, molybdenum, and silver ores are mined from two large open pit operations. The geologic history of the area has been influenced by the WNW-trending Silver Bell Fault Zone, which has served to localize the intrusion of shallow-level stocks and sills into country rocks consisting of limestone, volcanic, and earlier intrusive rocks. Mineralization accompanied hydrothermal alteration of the dacite, alaskite, and monzonite host rocks. These have been altered to mineral assemblages dominated by the presence of hydroxyl-bearing minerals (such as kaolinite, sericite, white mica), pyrite, and iron oxide/hydroxides. The iron oxide minerals have diagnostic absorption bands in the 0.45 and 0.85 μm regions of the spectrum, and the hydrous minerals are characterized by an absorption band in the 2.2 μm region and high reflectance near 1.6 μm

(Hunt, 1977). These features make the presence of these minerals discernible using the TM spectral bands.

Aircraft Thematic Mapper simulator data were resampled to produce 30 m pixels. A color ratio composite, consisting of band ratios $1.6 \mu\text{m}/2.2 \mu\text{m}$, $0.66 \mu\text{m}/0.56 \mu\text{m}$, and $0.83 \mu\text{m}/1.65 \mu\text{m}$ displayed as red, green, and blue, respectively, was produced to highlight the presence of alteration associated minerals (Figure 1a). Areas with iron oxides present are displayed in green, areas with hydrous minerals in red, and where both occur, a yellow color results. Superimposed on the image is the outline of the phyllic alteration zone (intense alteration with clays, sericite, and pyrite) from company field mapping. The correspondence with the altered zone depicted on the image is almost perfect.

A 12 by 15 km subarea of a Landsat-4 Thematic Mapper scene (30 m pixel size), acquired November 11, 1982, was extracted from the TM data. A color ratio composite using the same components as the simulator image was produced from the TM data. While the alteration zone was similarly displayed, the presence of periodic horizontal striping in the TM data produced an objectionable image. Therefore an alternative processing scheme was used.

The data were processed using a "decorrelation stretch" (Soha and Schwartz, 1978), which is based upon a principal components transformation. The uncorrelated data are subsequently stretched to equalize their variance, and the inverse transformation is applied to return to the original coordinate space. The effect of this procedure is to greatly

exaggerate color saturation and intensity, while preserving hue information. Figure 1b is a color additive composite of TM bands 7, 5, and 1 displayed as red, green, and blue, respectively, after decorrelation stretching.

In the resulting image, the alteration zone (area A) is displayed in bright green due to the high reflectance of altered rocks in the 1.6 μ m region. In addition, several other rock types are separable on the image based on color differences (Table 2). (These units are also separable on other aircraft simulator images, which are not shown here.)

The Landsat-4 TM data, with the same spectral bands as the aircraft simulator data, also allow identification of hydrothermal alteration zones based on detection of spectral features associated with hydroxyl-bearing and iron oxide minerals. It is the position of the spectral bands, rather than the particular image processing algorithm used, that allows this identification to be made, thus confirming the results of previous TM simulator data analysis.

One of the advantages of the TM data is its synoptic, global coverage, which permits examination of large areas of the earth's surface in a single scene under uniform illumination conditions. Another advantage is the narrow scan angle of the TM instrument (14.5°) compared to the aircraft simulator (90°). The narrow scan angle greatly reduces differential atmospheric effects, that appear as brightness gradients in scanner image data. These effects are difficult to model and remove in aircraft data, but are minimal in the TM images.

The comparison of TM simulator and Landsat-4 TM data confirms the

utility of the Thematic Mapper data for identifying hydrothermal alteration zones, often associated with base metal deposits. The spectral bands of the TM allow detection of hydroxyl-bearing minerals and iron oxides, major constituents of altered rocks. The TM provides geologists with a powerful new exploration tool for the worldwide search for undiscovered mineral deposits.

The work described in this paper was performed at the California Institute of Technology, Jet Propulsion Laboratory, under contract with the National Aeronautics and Space Administration.

Table 1. Spectral bands of TM and TM Simulator

TM		TM Simulator	
<u>Band</u>	<u>Wavelength (μm)</u>	<u>Band</u>	<u>Wavelength (μm)</u>
1	0.45-0.52	1	0.45-0.52
2	0.52-0.60	2	0.52-0.60
3	0.63-0.69	3	0.63-0.69
4	0.76-0.90	4	0.76-0.90
5	1.55-1.75	5	1.00-1.30
6	10.4-12.5	6	1.55-1.75
7	2.08-2.36	7	2.08-2.36
		8	10.4-12.5

Table 2. Key to Symbols on Landsat-4 TM Image

<u>Symbol</u>	<u>Description</u>
A	Phyllic alteration
B	Altered monzonite
C	Limestone
D	Basalt
E	Red beds
F, FF	Mt. Lord ignimbrite
G	Silver Bell andesite, mudflows
H	Claflin Ranch conglomerate, agglomerate
I	Granodiorite
J	Ragged Top latite
K	Precambrian schist/granite
L, LL	Dacite
M	Mixed intrusives
N	Limestone

References

- Abrams, M., Conel, J., and Lang, H., 1983, The Joint NASA/Geosat Test Case Project, Jet Propulsion Laboratory Technical Report, Pasadena, CA, in press.
- Hunt, G., 1977, Spectral Signatures of Particulate Minerals in the Visible and Near Infrared, Geophysics, Vol. 42, p. 501-513.
- Soha, J., and Schwartz, A., 1978, Multispectral Histogram Normalization Contrast Enhancement, 5th Canadian Symposium on Remote Sensing, Victoria, British Columbia, August, 1978, p. 86-93.

Figure Captions

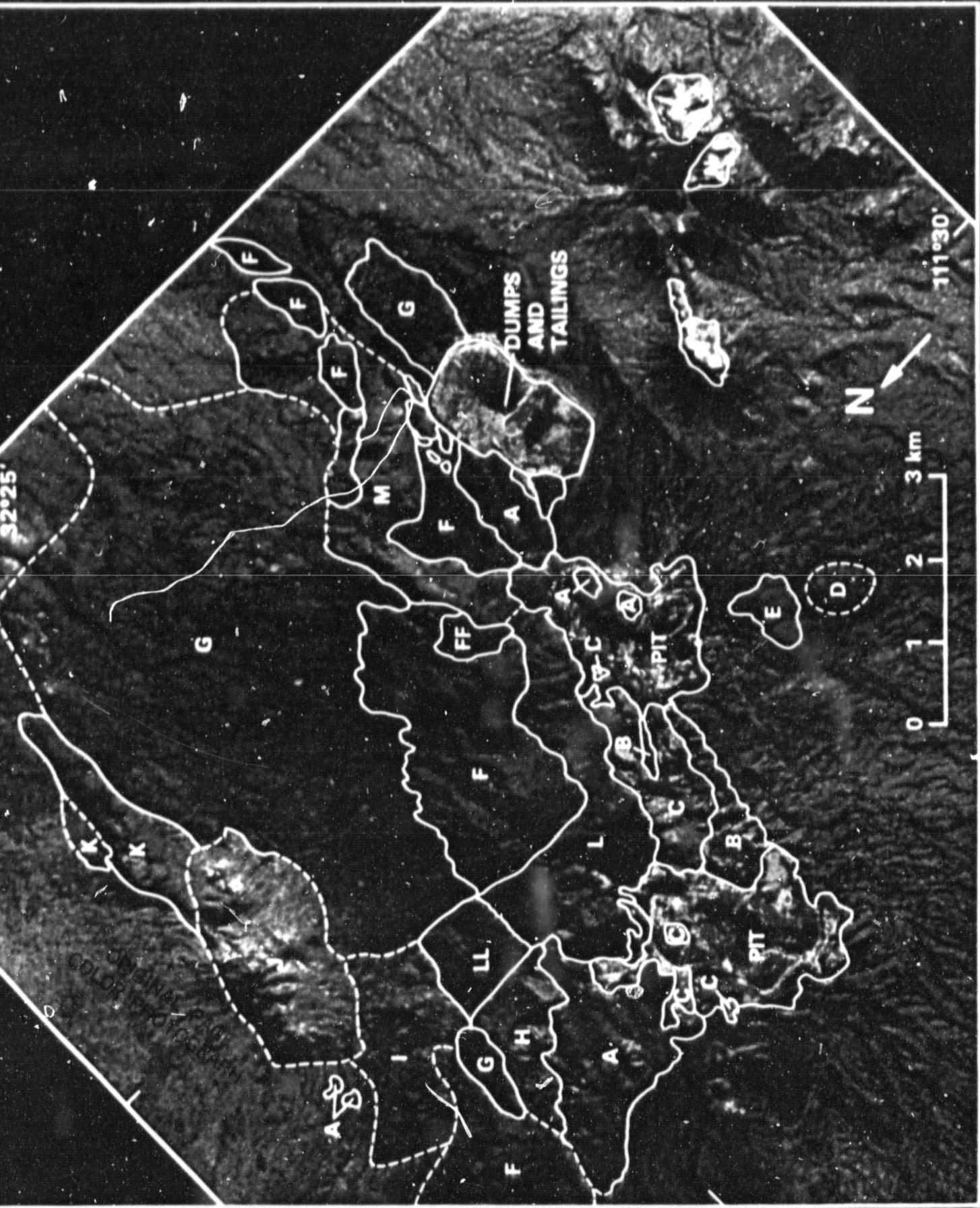
- 1a. Aircraft Thematic Mapper simulator data over the Silver Bell copper deposit, Arizona, resampled to 30 m pixel size. Band ratios $1.6 \mu\text{m}/2.2 \mu\text{m}$, $0.66 \mu\text{m}/0.56 \mu\text{m}$, and $0.83 \mu\text{m}/1.65 \mu\text{m}$ displayed as red, green, and blue, respectively. The main alteration zone is displayed in yellow due to the presence of hydroxyl-bearing and iron oxide minerals. Data acquired October 22, 1978.

- 1b. Landsat-4 TM data over the Silver Bell copper deposit, Arizona. Bands 7 ($2.2 \mu\text{m}$), 5 ($1.6 \mu\text{m}$), and 1 ($0.48 \mu\text{m}$) displayed as red, green, and blue, respectively. The main alteration zone is displayed in green due to the high reflectance of hydroxyl-bearing minerals in the $1.6 \mu\text{m}$ region. Scene No. 40128-17263, acquired November 11, 1982.

SILVER BELL COPPER DEPOSIT, ARIZONA
TM SIMULATOR DATA, 30 M
OUTLINED AREA FROM COMPANY ALTERATION MAP



ORIGINAL PAGE
 COLOR PHOTOGRAPH



GEOLOGIC UTILITY OF LANDSAT-4 TM DATA

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GEOLOGIC UTILITY OF LANDSAT-4 TM DATA

INTRODUCTION

The present LIDQA study is being conducted in several phases to quantify the performance of the TM vis-a-vis various geological applications. These phases include: (1) analyses of the geological utility of the data with respect to the increased spatial resolution and number of bands (compared to the MSS); (2) analysis of geometric accuracy; (3) analysis of radiometric performance of the TM scanner.

Preliminary analyses have been performed on two TM scenes: E-40124-17495 over Death Valley, California, and E-40128-17263 over southern Arizona. Both scenes were acquired in CCT-PT format, where the data were geometrically and radiometrically corrected. Overall, the TM data appeared to contain a marked increase in geologically useful information; however, a number of instrumental or processing artifacts may well limit the ability of the geologist to fully extract this information.

DEATH VALLEY SCENE

In order to examine the utility of the TM data at full usable spatial resolution, several small areas were extracted from the TM scene for further image processing. A 27 by 18 km area was examined covering the east side of the Panamint Mountains, alluvial fans descending to the valley floor, part of the Death Valley salt pan, and Trail Canyon. Data were processed using band ratioing, color-enhanced band composites, and principal components transformations. Lithologic interpretation maps were prepared and compared to published geologic maps of the area. More detail and delineation of alluvial fan units were evident on the TM scene. Relative ages of the fans could be inferred based on geomorphic appearance. The oldest fans had dendritic drainage patterns developed on their surfaces, while younger fans were characterized by the

presence of parallel to braided drainage patterns. The 28.5 m pixel size was more than sufficient to resolve these drainage features. Spectral contrast between fans was related to differences in source rock composition and variable development of weathering and varnish surfaces. In combination with the spatial details, all mapped fan units were separable, and additional separations based on spectral differences could be made. Of the three different enhancement procedures used, ratioing produced the least useful images due to exaggeration of noise and artifacts (discussed later).

A second area, 15 by 15 km over the Tucki Mountains at the northwest end of Death Valley, was extracted from the TM scene to examine the utility of the data for separating sedimentary rock types. The Tucki Mountains have exposed quartzites, shales, dolomites, limestones, and sandstones. The beds dip 50°-90°, and topographic relief is rather severe. However, exposures are excellent as vegetation cover is minimal to absent. Again the principal components composites and enhanced-band composites were the most satisfactory for display of the data. Many of the mapped rock types were separable based on spectral differences. Problems occurred along north-facing slopes due to deep shadows resulting from the low sun angle (27°) during the November data acquisition; no lithologic information was discernible in these shadowed areas.

The same two areas were extracted from Landsat-2 MSS data for comparison to the TM data. The improvement in spatial resolution of the TM was patently apparent. No details of the drainage patterns on the fans were discernible on the MSS data, making interpretation of geomorphic information impossible. In addition, the limited spectral band coverage reduced the amount of lithologic separations displayed on the images.

A larger area (60 by 40 km) was processed to examine the effects of using different spectral channels in false color composites. The data were processed using decorrelation stretching (Soha and Schwartz, 1978) and combined in various triplets to produce a color composite (described in a later section). The most useful combination examined was created using bands 4, 5, and 7--the three infrared bands. This is not surprising, as the major spectral contrast between different rock types occurs in the infrared part of the spectrum. This points out one of the main advantages of the TM over MSS data--the presence of channels beyond 1.0 μm .

We have digitally registered the TM data to a topographic map base, then registered Seasat radar data and six channels of thermal multispectral aircraft data (8.2-12.2 μm range) to this data base. The objective is to assess the improvement in material separation possible using this multivariable data set. Each data set measures a different surface physical property--the TM is sensitive to reflectance characteristics which are mainly controlled by the presence of iron, water, hydroxyl ion, and carbonate ion, and overall brightness or albedo; the thermal data are sensitive to the presence of free silica, hydroxyl ion, density, albedo, conductivity, and diffusivity; the Seasat data are sensitive to surface roughness, orientation, and moisture content.

A principal components transformation was applied using 13 input variables: six TM bands excluding thermal, six thermal multispectral scanner bands, and one Seasat channel. Composites were created using various triplets of the eigenpictures, and two were selected for separation of fan units and rock units.

Both composites had more information displayed using the combined data set than was apparent in images created from any of the data sets alone. Further processing and analysis of these data will continue to assess the contribution of the data types for separating various types of materials.

SILVER BELL AREA

A 30 by 45 km area was extracted from the southern Arizona TM scene over the Silver Bell porphyry copper deposit. This area was intensively studied in the past during the Joint NASA/Geosat test case project (Abrams et al., 1983). A number of extrusive and intrusive rocks are exposed, in addition to limestone and alluvium. A major hydrothermal alteration event produced a varied assemblage of minerals related to hydrothermal activities and deposited copper and molybdenum. These minerals have spectral characteristics which occur in the 0.4 to 2.5 μ m wavelength region, and were detectable using Thematic Mapper Aircraft Simulator data.

A number of processing techniques were applied to the TM data; the most satisfactory (least objectionable noise) was decorrelation stretching. Color composites produced using visible and infrared channels reproduced the alteration separation derived from the aircraft data. This confirmed the earlier predictions that the TM data, at a resolution of 30 m, would be useful for detecting mineralogical features associated with this type of ore deposit.

PROCESSING TECHNIQUES AND NOISE

Band ratioing, a technique which has produced satisfactory results with the MSS data, suffers from a severe noise problem using the TM data. Specifically, the ratioing process exaggerates the presence of striping in the TM data. This striping is apparent in the individual TM channels; it has a 17 line periodicity, and in some bands consists of a pair of bad data lines, with the appearance of salt-and-pepper noise. The bad lines occur at the joins between the forward and reverse scan directions. The cause of the 17 line periodicity may be a result of the geometric resampling performed on the data to produce 28.5 m pixels from 30 m data. Notice that the ratio $28.5/30 = .950$, and $16/17 = .941$. This suggests that the interpolation algorithm used to produce the added lines of data is functioning improperly. Also, the bad lines occur where differences in the radiometry between the forward and reverse scans would be most apparent--at the join between them. This type of noise--coherent, along-line striping--can be readily removed using the following procedure:

- 1) The average of each line is computed and retained as a one-column image = A;

- 2) This image is low-pass filtered with an equal weight filter = B;

- 3) The one-column difference picture (A-B) is calculated, and then expanded to the full picture dimensions. That is, a picture with the same number of columns as the original is created, with each of its columns being identical with (A-B);

4) The above picture is subtracted from the original to produce the end result, an image without striping.

Principal components analysis applied to the 6 visible and near-infrared channels produced eigenpictures with the striping distributed in the last three components (the fourth, fifth, and sixth). A composite using the first three components was devoid of striping; however, the last three contained meaningful information. Composites made with any of these added striping into the color composite.

The most generally useful display technique, which enhanced the information content without exaggerating the striping, is a procedure called decorrelation stretch. The six TM channels were input to a principal components transformation; the data were stretched to equalize the variance between components; the inverse rotation was performed, which rotated the data back to the original coordinate space. The effect of this procedure is to greatly exaggerate saturation and intensity variations, while preserving the hue content. Any triplet combination of enhanced channels can then be used to produce a false color composite.

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- Abrams, M., Conel, J., and Lang, H., 1983, "The Joint NASA/Geosat Test Case Project," Jet Propulsion Laboratory Technical Report, Pasadena, CA, in press.
- Soha, J. and Schwartz, A., 1978, "Multispectral Histogram Normalization Contrast Enhancement," Proceedings of 5th Canadian Symposium on Remote Sensing, Victoria, August 1978, pp. 86-94.