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Landsat-4 Thematic Mapper and Thematic Mapper Simulator Data for a Porphyry Copper Deposit

Both aircraft Thematic Mapper simulator data and Landsat-4 satellite data over a porphyry copper deposit in Arizona allowed detection of the alteration zone associated with mineralization and discrimination of various other rock types.

AIRCRAFT THEMATIC MAPPER (TM) simulator data were acquired in 1978 as part of the Joint NASA/Geosat Test Case Project (Abrams *et al.*, 1984) 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 United States, 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 west northwest-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/hydroxide minerals. 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 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 μm/2.2 μm, 0.66 μm/0.56 μm, and 0.83 μm/1.65 μm displayed as red, green, and blue, respectively, was produced to highlight the presence of alteration associated minerals (Plate 1). Areas with iron oxides present are displayed in green, areas with hydrous minerals (and vegetation in the stream beds) 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 provided field maps. The correspondence with the altered zone depicted on the image is almost perfect.

A 12- by 15-km subarea of a Landsat-4 Thematic

TABLE 1. SPECTRAL BANDS OF TM AND TM SIMULATOR

TM		TM Simulator	
Band	Wavelength (μm)	Band	Wavelength (μm)
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	1.00–1.30
5	1.55–1.75	6	1.55–1.75
7	2.08–2.36	7	2.08–2.36
6	10.4–12.5	8	10.4–12.5

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PLATE 1. Aircraft Thematic Mapper simulator data over the Silver Bell copper deposit, Arizona, resampled to 30-m pixels. Band ratios 1.6 μm/2.2 μm, 0.66 μm/0.56 μm, and 0.83 μm/1.65 μm 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 22 October 1978.

PLATE 2. Landsat-4 TM data over the Silver Bell copper deposit, Arizona. Bands 7 (2.2 μm), 5 (1.6 μm), and 1 (0.48 μm) 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-μm region. Scene 40128-17263, acquired 11 November 1982.

TABLE 2. KEY TO SYMBOLS ON LANDSAT-4 TM IMAGE

Symbol	Description
A	Phyllic alteration
B	Altered monzonite
C	Limestone
D	Basalt
E	Redbeds
F,FF	Mt. Lord ignimbrites
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

Mapper scene (30-m pixel size), acquired 11 November 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 due to residual detector miscalibrations 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. Plate 2 is a color additive composite of TM bands 7, 5, and 1 displayed as red, green, and blue, respectively, after decorrelation stretching. (Note that horizontal striping is still evident in the image).

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 μm region. A smaller green zone (K) in the Precambrian rocks to the north is also altered. The limestones (C) in the altered zone have been converted to skarn, and appear different from the unaltered limestones at N. In addition to the discrimination of altered rocks, 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 in arid regions, 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 analyses.

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 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.

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REFERENCES

Abrams, M., J. Conel and H. Lang, 1984. *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, *Goephysics*, Vol. 42, pp. 501-513.

Soha, J., and A. Schwartz, 1978. "Multispectral histogram normalization contrast enhancement", 5th Canadian Symposium on Remote Sensing, Victoria, British Columbia, August, 1978, pp. 86-93.

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