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PRINCIPLES OF COMPUTER PROCESSING OF LANDSAT DATA FOR GEOLOGIC APPLICATIONS

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PRINCIPLES OF COMPUTER PROCESSING OF LANDSAT DATA

FOR GEOLOGIC APPLICATIONS

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ABSTRACT

The main objectives of computer processing of Landsat data for geologic applications are to improve display of image data to the analyst or to facilitate evaluation of the multispectral characteristics of the data. Interpretations of the data are made from enhanced and classified data by an analyst trained in geology. Image enhancements involve adjustments of brightness values for individual picture elements. Image classification involves determination of the brightness values of picture elements for a particular cover type. Histograms are used to display the range and frequency of occurrence of brightness values.

Landsat-1 and-2 data are preprocessed at Goddard Space Flight Center (GSFC) to adjust for the detector response of the multispectral scanner (MSS). Adjustments are applied to minimize the effects of striping, adjust for bad-data lines and line segments and lost individual pixel data. Because illumination conditions and landscape characteristics vary considerably and detector response changes with time, the radiometric adjustments applied at GSFC are seldom perfect and some detector striping

remain in Landsat data. Rotation of the Earth under the satellite and movements of the satellite platform introduce geometric distortions in the data that must also be compensated for if image data are to be correctly displayed to the data analyst. Adjustments to Landsat data are made to compensate for variable solar illumination and for atmospheric effects. Geometric registration of Landsat data involves determination of the spatial location of a pixel in the output image and the determination of a new value for the pixel.

The general objective of image enhancement is to optimize display of the data to the analyst. Contrast enhancements are employed to expand the range of brightness values in Landsat data so that the data can be efficiently recorded in a manner desired by the analyst. Spatial frequency enhancements are designed to enhance boundaries between features which have subtle differences in brightness values. Ratioing tends to reduce the effects due to topography and it tends to emphasize changes in brightness values between two Landsat bands. Simulated natural color is produced for geologists so that the colors of materials on images appear similar to colors of actual materials in the field.

Image classification of Landsat data involves both machine assisted delineation of multispectral patterns in four-dimensional spectral space and identification of machine delineated multispectral patterns that represent particular cover conditions. The geological information derived from an analysis of a multispectral classification is usually related to lithology.

INTRODUCTION

When Landsat 1 was launched in 1972 the U.S. Geological Survey expanded its research in digital image processing to include Landsat data. Research in computer processing of Landsat data for geological applications was conducted in the Survey's Geologic Division by two organizations - The Center for Astrogeology in Flagstaff, Arizona and the Branch of Petrophysics and Remote Sensing in Denver, Colorado. Much of this research was conducted jointly with the Image Processing Laboratory in the Jet Propulsion Laboratory of the California Institute of Technology in Pasadena, California. This material is developed largely from publications of these three organizations. Users of this material should consult the publications listed in the bibliography. This text is a supplement to a 2-hour slide-illustrated lecture and workshop exercises used for training courses in geologic remote sensing. Slides of illustrations are available from the EROS Data Center User Services Section if their Public Affairs Office (PAO) numbers are referenced.

IMAGE PROCESSING FOR GEOLOGIC APPLICATIONS

The main objectives of computer processing of Landsat data are to improve display of image data to the analyst or to facilitate evaluation of the multispectral characteristics of the data. Digital processing techniques are readily employed with Landsat data because:

1. The original data are in digital form.
2. Errors in the data introduced by the system can be rectified.
3. Adjustments for sun illumination and atmospheric effects can be applied.

4. Individual picture elements can be analyzed and displayed.

5. Mathematical processing functions can be utilized.

6. Statistical analysis techniques can be employed.

7. Large amounts of data may be processed and analyzed in short periods of time.

Most digital image processing involves three procedures: data preprocessing, image enhancement, and image classification (figure 1).

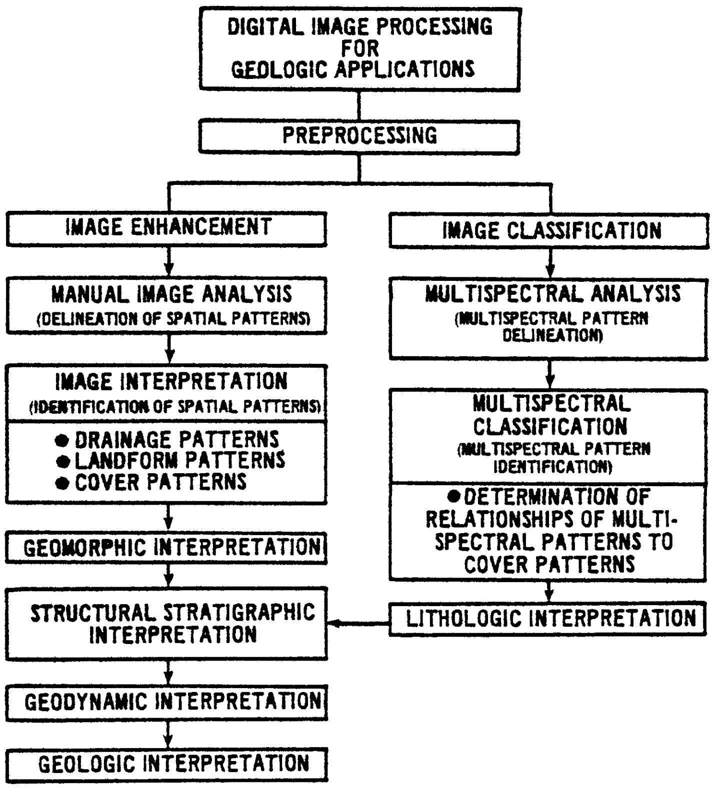


Figure 1.--Procedures for digital image processing for geologic applications. PAO Number: E-6211-35.

Data preprocessing includes the adjustment of system introduced errors, adjustment for atmospheric and solar illumination variations, and registration of data. Image enhancement is performed to make spatial patterns, displayed in tones and color, more apparent on imagery. Image classification is performed to delineate multispectral patterns in image data.

Geologic interpretations are developed from enhanced and classified image data through the use of a stepwise procedure which must involve an interpreter with training in geology. Manual image analysis involves delineation of spatial patterns on imagery. Image interpretation involves identification of spatial patterns on imagery as landform, drainage, and cover patterns. An image analyst with training in geology must analyze the landscape patterns on imagery to interpret geomorphology. Geomorphologic relationships are analyzed to develop structural and stratigraphic relationships. Geologic interpretations are developed through a correlation of geodynamics, structure, stratigraphy, and geomorphology. Multispectral pattern analysis involves machine assisted multispectral pattern delineation. Multispectral classification of delineated multispectral patterns must be done by an analyst who determines the relationships of multispectral patterns to landscape cover patterns. If a strong relationship exists between the economic deposits sought and the cover patterns (for example, between base metals and surface alteration zones), then an exploration plan may be developed on the basis of an image classification. Usually multispectral classifications must be incorporated with structural and stratigraphic interpretations, and the resource exploration plan must be based on a geologic interpretation which is ultimately developed from both spatial and multi-spectral patterns in the image data, and from geologic information from other data sources.

HISTOGRAMS OF BRIGHTNESS VALUES

Image enhancements and image classifications often involve the evaluation of histograms of the data to be processed. Image enhancements involve adjustments of brightness values (see Taranik, 1978 p. 29 for explanation of brightness value concept) for individual picture elements. Image classification involves determination of the brightness values of picture elements for a particular cover type. Histograms are commonly used to display the range and frequency of occurrence of brightness values. A spatial array of picture elements in part of one Landsat band is shown in figure 2. A histogram of the pixel values in the spatial

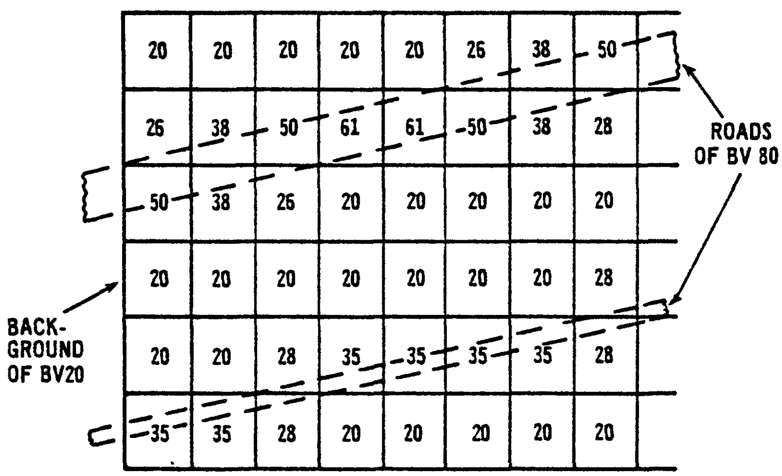


Figure 2.--Spatial array of pixels and their brightness values (BV's) in a portion of one Landsat spectral band. PAO Number: E-6329-35.

array is shown in figure 3. An image enhancement technique might shift

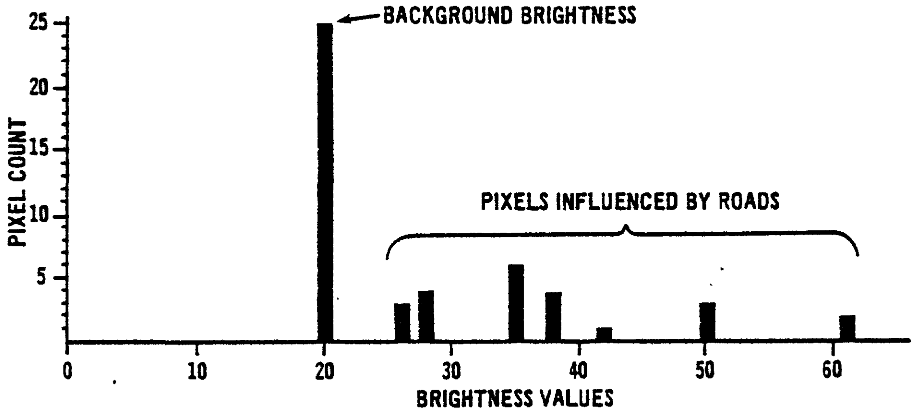


Figure 3.--Histogram of the brightness values of pixels in a spatial array. PAO Number: E-9393-35.

brightness values so only brightness values associated with roads are shifted to the right on the histogram. Thus there would be a larger brightness differential between roads and the background against which roads were imaged. An image classification technique might group brightness values associated with roads in four spectral bands.

Because one Landsat scene contains 7,581,600 picture elements (pixels which have four values) it is not practical to display the total count of picture element brightness values graphically in a histogram. Histogram displays of a single band are usually "normalized" so that the maximum count of picture elements of one brightness value is displayed as 100% of the ordinate axis. All other counts of picture elements of a particular value that are less than the maximum count are adjusted relative to the maximum count so that they are percentages of the maximum count (figure 4). The abscissa usually has values of 0 to 127 for data

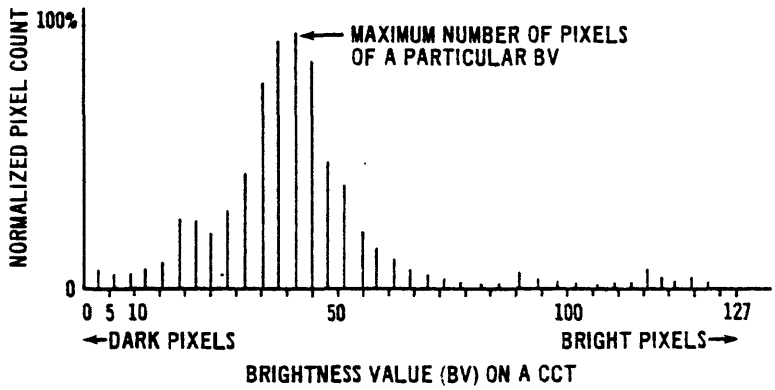


Figure 4.--Histogram of brightness values normalized to 100 percent maximum pixel count in one Landsat spectral band. PAO Number: E-6215-35.

from bands 4, 5, and 6, and values of 0 to 63 for data from band 7 if the data are read directly from a CCT. Most computer processing is done in 8-bit mode, and in this case, the histogram abscissas have values of from 0 to 255.

PREPROCESSING OF LANDSAT-1 AND-2 DATA

RADIOMETRIC RECTIFICATION

Landsat-1 and-2 data are converted from wide-band video tapes to film and computer compatible tapes at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. Preprocessing is done at GSFC to adjust for variations in the response of the 24 Multispectral Scanner (MSS) detectors. Because illumination conditions and landscape characteristics vary considerably and detector response changes with time, the radiometric adjustments for detector response are seldom perfect and usually detector striping remains on Landsat film and CCT products. Bad-data lines and line segments, and lost individual pixel data are also common radiometric defects in Landsat products.

Adjustments for Striping

Striping in Landsat data results from differences in the response characteristics of the 24 MSS detectors. Specifically, the detectors have different gains and offsets (figure 5). Methods for minimizing this

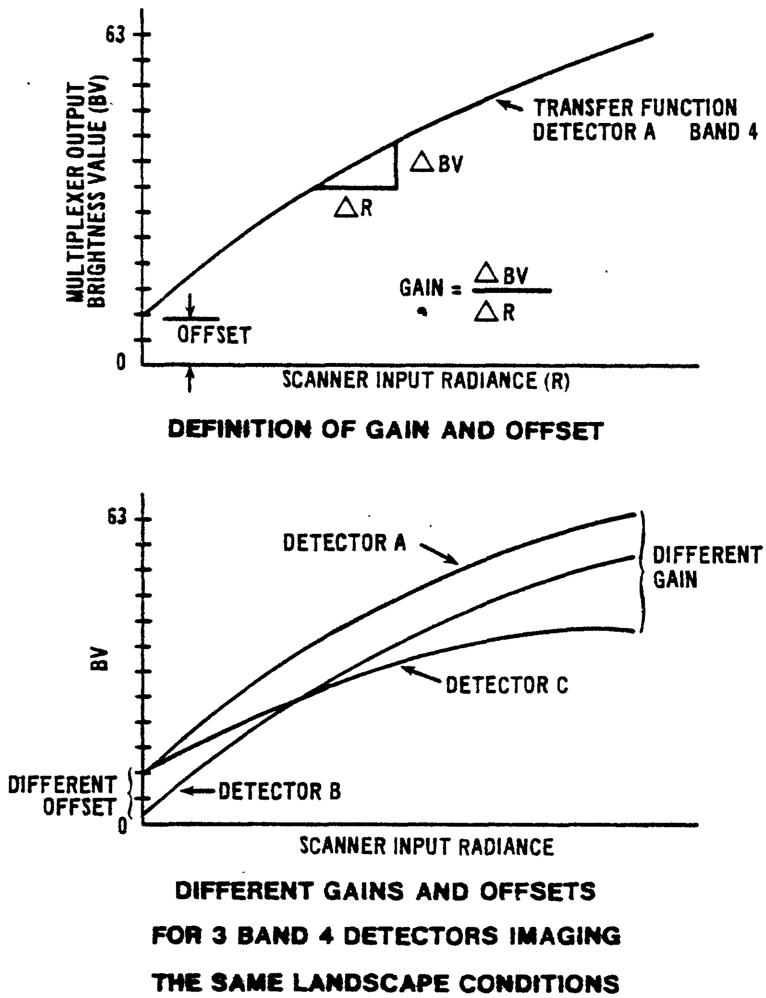


Figure 5.--Definition of gain and offset and their relationship in different detectors. PAO Number: E-6213-35.

problem include filtering, histogram normalization, and histogram normalization with local average adjustment. Histogram normalization with local average adjustment was the process employed by the EROS Data Center Digital Image Enhancement System (EDIES). The following description of the process is from Rohde, Lo, and Pohl, (1978): "Effects of striping in each MSS band are minimized by a two-pass operation. In the first pass, data from each detector are normalized with the relationship:

$$DN_O = DN_I \times \frac{S_A}{S_I} + (M_A - M_I \times \frac{S_A}{S_I}) \tag{1}$$

where:

DN_O = Brightness value of pixel in output image

DN_I = Brightness values of pixel in input image

S_A = Standard deviation of entire scene

S_I = Standard deviation of individual detector

M_A = Mean brightness value of entire scene

M_I = Mean brightness value of individual detector

The adjustment is based on statistics calculated from the entire scene. However, for some subregions of a scene the "local" statistics are quite different from statistics calculated from an entire scene. When this occurs, the one-pass algorithm may not be completely effective and some residual striping may remain. The second pass performs a local average adjustment to remove residual striping from the first pass. In the second pass, data are processed in groups of six lines (Chavez, 1975). The first line is chosen as a good data line and each succeeding line is processed to be similar to the preceding line. The first line remains unchanged as it is the reference line. A local average along line I ($LOCAV_I$) of plus or minus 75 pixels around the pixel being processed in a line is compared to the corresponding local average in the preceding line I-1 ($LOCAV_{I-1}$). Before pixels are used to compute the local average, the pixels are subjected to an edge test. If the absolute value of the difference between brightness values of pixels in adjacent scan lines is greater than a specified threshold value, it is assumed that a real edge exists in the data, and the pixels are not used to calculate the respective local averages. Once the local averages have been computed, the difference between the local average around a pixel in a given line and the local average around a pixel in the preceding line is computed. If the absolute value of this difference is less than a specified threshold value, the pixel brightness value is modified by the difference and is computed from the formula:

$$DN_O = DN_I - D$$

where:

DN_O = Digital number or brightness value in output image

DN_I = Digital number of brightness value in the input image

D = $LOCAV_{I-1}$

This second operation, although time-consuming, does appear to remove the residual striping that is often found when only the first operation is used."

Replacement of Bad-Data Lines

Two methods are commonly employed in replacing bad-data lines in Landsat data. One method uses an interpolation procedure to replace the bad-data line with values determined by interpolating between the brightness values in the preceding line and the line following the bad-data line. In the EDIES system a second technique was employed which replaced the brightness values in the bad-data line with values in the preceding line. Bad-data lines were identified in EDIES by calculating the standard deviations and mean values of the first six scan lines. By comparing these statistics, a "good" line was selected as the first reference line. Then a two-by-two pixel edge detector was applied to the reference line and the next scan line. The detector was moved horizontally across the scan lines one pixel at a time. The brightness values for the four pixels were subjected to a test. When the absolute value of a pixel in the next line and the line above was greater than a predetermined threshold value, a horizontal edge (bad-data point) was assumed. When 150 consecutive bad-data points were counted, the entire scan line was replaced by the brightness values in the entire line above (Rohde, Lo, Pohl, 1978).

GEOMETRIC RECTIFICATION

Landsat CCT data also have geometric characteristics which must be rectified if image data are to be correctly displayed to the analyst. Rotation of the Earth under the satellite and movements of the satellite itself introduce geometric distortions in the data.

Adjustment for Earth Rotation

The "skew" caused by rotation of the Earth under the satellite is a function of latitude and spacecraft heading. Each scene is deskewed by an algorithm that shifts scan lines to the right depending on the latitude of the line. This type of geometric adjustment insures that landscape features are in relative position with respect to each other throughout the scene.

Adjustment for Line Length

The variable velocity of the MSS mirror scanning mechanism and variations in the altitude of the satellite platform from 880 km to 940 km cause variations in the line length of MSS data. The correct line length, based on a model of orbital and instrument parameters is 3318 pixels. Landsat-1 and-2 data are adjusted to a line length of 3240 pixels at GSFC. The line length on most CCT's is about 3240 pixels; therefore, pixels are inserted at intervals to increase line lengths to 3318 pixels. This is done by using a piece-wise linear interpolation method. Each scan line is divided into eight equal segments, and each segment is partitioned into a given number of pixels (n). Ground displacement errors (d) for each segment are computed at GSFC. Each segment is then repartitioned into n + d equal parts. The center coordinates of each equal part is the new pixel location in that segment. The brightness value for each new pixel added to the line is derived by linear interpolation between the brightness values of the pixels on either side of the added pixel. This process is repeated for each of eight segments in all scan lines in the scene. Pixel insertion may cause some problems with viewing Landsat data in stereo using the slide-lapped portions of Landsat images because it may alter the relief displacement present in the uncorrected data.

Aspect Ratio Adjustment

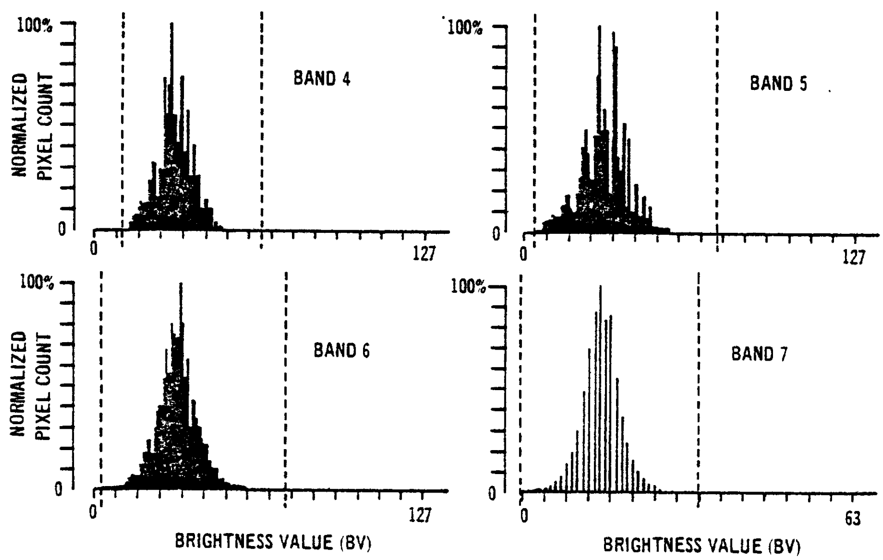
Some recording devices utilize a square recording aperature and an adjustment for rectangular Landsat pixels must be applied to the data to preserve geometric relationships. Often this adjustment is performed on the output device by repeating a line of output.

ADJUSTMENT FOR SOLAR ILLUMINATION

An adjustment applied for solar illumination is to adjacent scenes of Landsat data that are to be computer mosaicked and that were acquired under different illumination conditions. This type of adjustment is also necessary for comparison of spectral properties of cover types in scenes acquired under different conditions of solar illumination. The Sun elevation angle (Sun angle) adjustment is made by multiplying all brightness values in a scene by a constant that is a function of the Sun angle. The function assumes a Lambertian surface and is derived by dividing the pixel brightness by the cosine of the incidence angle (Chavez, 1975). This adjustment does not remove the effects of topography which influence the amount of solar radiation per unit area (solar flux) received by slopes facing toward and away from the Sun (Taranik and Trautwein, 1977). The adjustment also does not correct for differences in solar illumination caused by changes in the azimuth of illumination.

ADJUSTMENT FOR ATMOSPHERIC EFFECTS

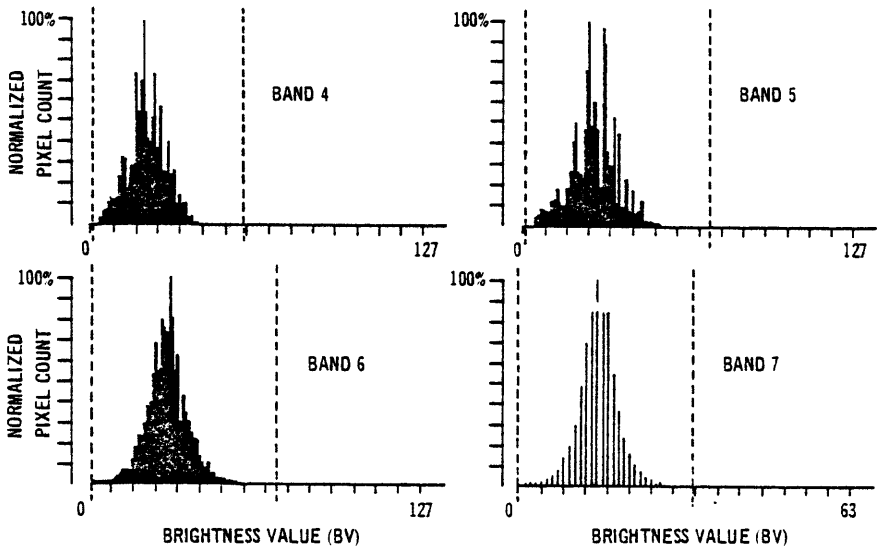
The atmosphere affects data acquired by the Landsat MSS in two ways. Atmospheric scattering adds brightness values to the data that are inversely proportional to the fourth power of the wavelength. Short wavelengths of electromagnetic radiation are therefore affected more than longer wavelengths. Atmospheric absorption subtracts brightness from the longest wavelength interval detected by the MSS (band 7) (see Taranik, 1978, p. 39). These effects commonly cause data from band 7 to have zero brightness even when no objects of zero reflectance are in the scene and cause the darkest pixels in 6, 5, and 4 to have respectively increasing brightness values. These relationships are shown on figure 6,



SPECTRAL BAND	LOW BOUND BV	HIGH BOUND BV
Band 4	11	60
Band 5	4	69
Band 6	3	69
Band 7	0	31

Figure 6.--Histograms showing the distribution of brightness of Landsat data values prior to adjustment of Landsat data for atmospheric scattering for an area in the Powder River Basin.

which is a reproduction of actual data for a "hazy" scene in Wyoming. The lowest brightness value in band four is 11, the lowest brightness value in band five is 4, the lowest brightness level in band six is 3, and band seven has a lowest brightness value of 0. If the histograms of bands 4, 5, and 6 are shifted to the left so that zero values appear in data, then the effects of atmospheric scattering will have been minimized (this is often called "haze removal," Chavez, 1975). The displacement of values is accomplished by subtracting the lowest brightness value in a band from all brightness values in the band (figure 7).



SPECTRAL BAND	LOW BOUND BV	HIGH BOUND BV
Band 4	0	49
Band 5	0	65
Band 6	0	66
Band 7	0	31

Figure 7.--Histograms showing the distribution of brightness values of Landsat data after adjustment of Landsat data for atmospheric scattering for an area in the Powder River Basin.

Normally this operation is accomplished during a contrast stretch of the data because data values are expanded over the entire brightness value range between 0 and 127, or 0 and 255 if the data are scaled to 8-bit mode.

Adjustments for atmospheric absorption are difficult to determine because atmospheric absorption is largely a function of water vapor in the atmosphere. The amount of water vapor may be variable from scene to scene, but can usually be modeled for one scene if sufficient weather station data is available on total precipitable water for the date and time that the satellite data were acquired. Atmospheric scattering and absorption greatly influence the measurement of spectral characteristics of cover conditions. If comparisons are to be made between ground-based spectral measurements and satellite measurements then corrections for atmospheric effects must be applied.

GEOMETRIC REGISTRATION

Geometric registration of Landsat data to a map projection, to other Landsat scenes, or to data from other sources, involves two basic steps. The first step involves determination of the spatial location of a pixel in the output image. The second step is to determine the new value for the pixel in the output image. Spatial mapping transformations are usually applied to the data to determine the locations of output pixels. The locations of output pixels will rarely coincide with the locations of pixels in the input image, and thus pixel values for the output image will have to be interpolated from adjacent input pixels. This procedure is commonly referred to as resampling. Three commonly used resampling techniques are nearest neighbor, bilinear interpolation, and cubic convolution. In nearest neighbor interpolation values equal to that of the nearest input pixel are assigned to the output pixels (figure 8). In bilinear interpolation values are assigned to output

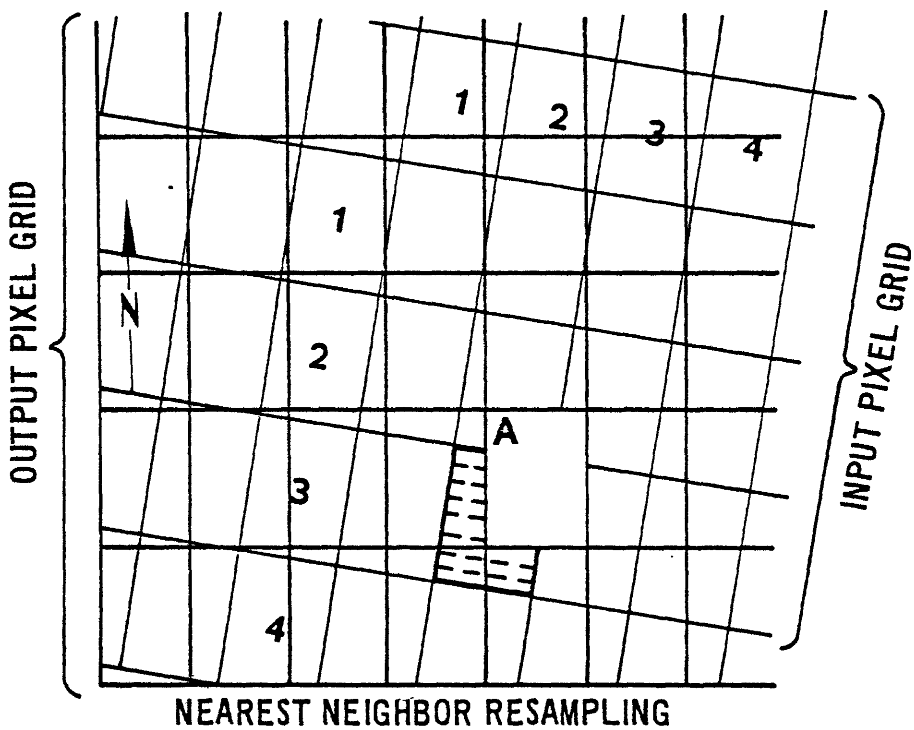


Figure 8.--Nearest neighbor resampling. Pixel A is the pixel in the output image. Input pixel grid is skewed with respect to North. Value of Pixel A is determined from shaded, nearest pixel.

pixels by interpolation in two orthogonal directions. The values of input pixels on either side of the output pixel are weighted using the linear distance between the centers of the input pixels and the center of the output pixel (figure 9). The average value of the four weighted digital numbers of the input pixels is the digital number for the output pixel. Cubic convolution resampling assigns values to ouput pixels much in the same manner as bilinear interpolation, except that the weighted

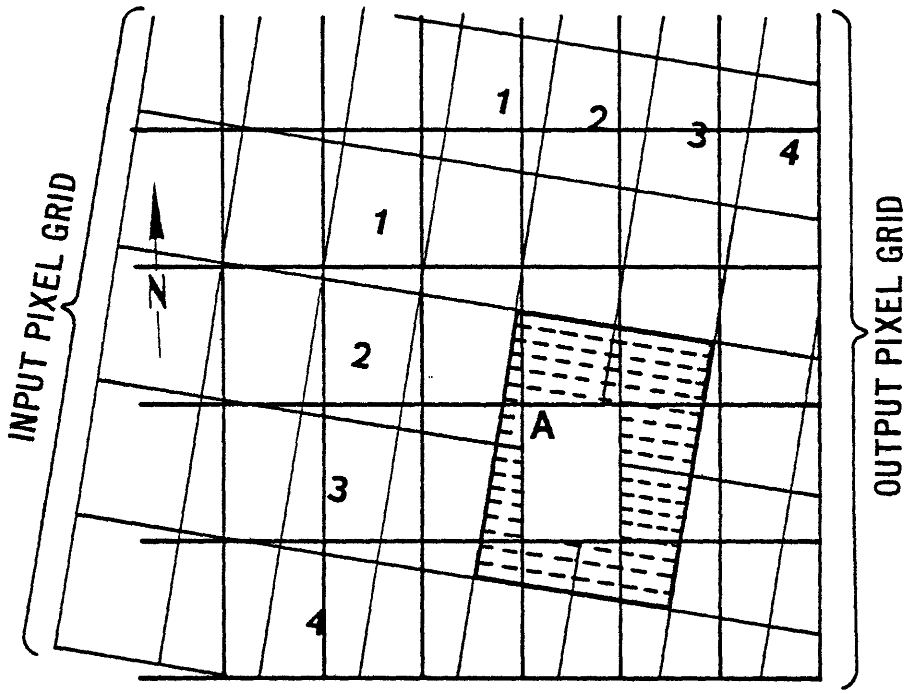


Figure 9.--Bilinear interpolation. Pixel A is the pixel in the output image. The value of A is determined from the weighted values of the surrounding 4 pixels in the input image.

values of 16 input pixels that surround the new pixel are used to determine the value of the output pixel.

IMAGE ENHANCEMENT

The general objective of image enhancement is to optimize display of the data to the analyst. Most image analyst-interpreters work with photographic images - film or print materials. The manner in which brightness values on a computer tape are recorded as densities on film is critical to an understanding of image enhancement. In fact, unless great care is taken to calibrate the photographic reproduction system, the results of carefully planned computer image enhancement may be spoiled by a poor job of film recording (figure 10). The relationships

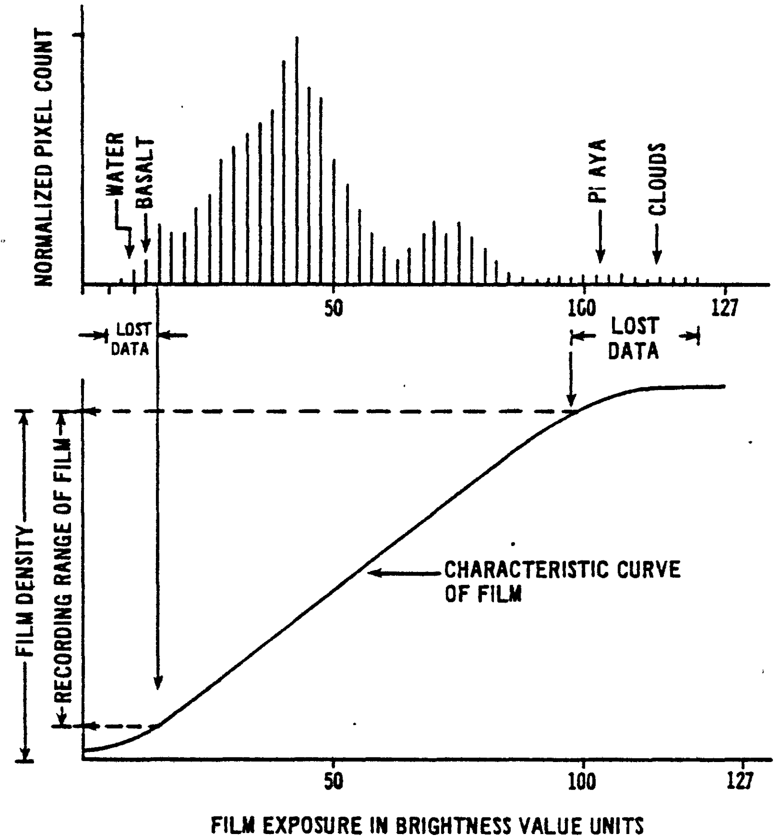


Figure 10.--Undesirable relationships between brightness values on an input CCT and output film density. After Ragland and Chavez (1976). PAO Number: E-6216-35.

shown in figure 10 are not desirable for a film recording system. Some data are lost, not by selection of digital processing parameters, but by the characteristics of the recording film. Ideally, the recording characteristics of the film system should not allow data to be lost (figure 10). Either the range of brightness values should be restricted so it falls on the straight line portion of the film characteristic curve, or a different film recording medium should be selected which allows all brightness values to be recorded as discrete density levels on film (Lucas, Taranik and Billingsley, 1977a).

CONTRAST ENHANCEMENT

Linear Contrast Enhancement

The concept of linear contrast enhancement of Landsat digital data is shown in figure 11. Most digital computer systems work in an 8-bit

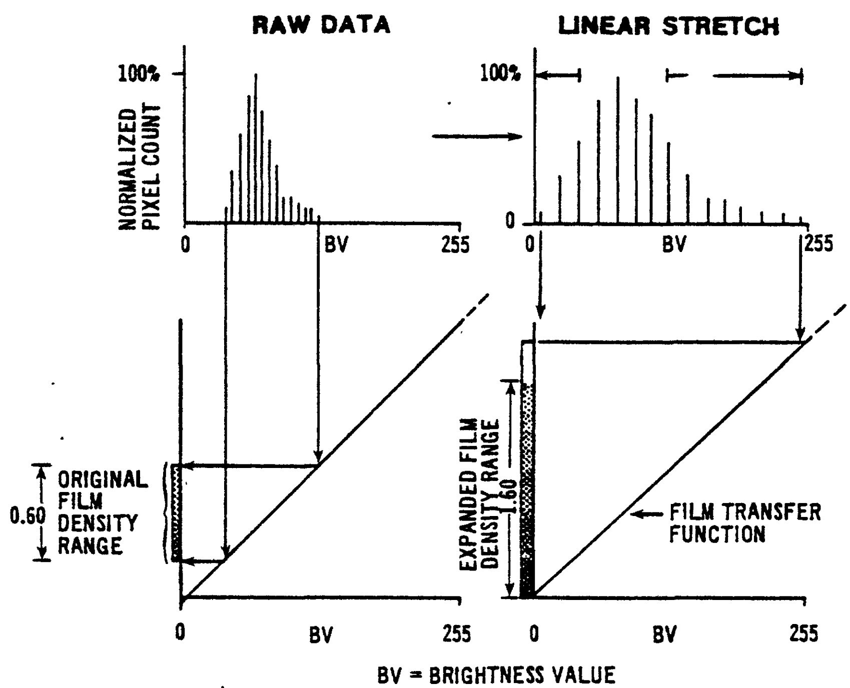


Figure 11.--Concept of linear contrast enhancement. PAO Number: E-6217-35.

mode so Landsat data either are scaled 0-255 prior to enhancement or they are distributed over this range during enhancement (figure 11). Linear contrast enhancement is done by assigning new brightness values to each pixel in the scene in a manner expressed by the following equation 3 (Rohde, Lo, and Pohl, 1978):

$$BV_O = \frac{BV_I - MIN}{MAX - MIN} \times 255 \quad (3)$$

where:

BV_O = Enhanced brightness value of pixel in output image

BV_I = Brightness value of pixel on CCT (input value)

MIN = Minimum brightness value parameter

MAX = Maximum brightness value parameter

Brightness value parameters are usually determined by an analyst (saturated to black or white by truncation), who determines what data are to be lost, reassigned to maximum and minimum values on the output image. The analyst does this by examining histograms or by interactively determining the truncation limits. Sometimes automatic truncation limits can be established by using a rule that a certain percentage of the data are to be truncated on either end of the histogram. The EDIES products produced at EDC had brightness value parameters determined on an interactive multispectral analysis computer which allowed the analyst to visually determine which picture elements on the imagery would be truncated; this technique is described by Lucas, Taranik, and Billingsley (1976). When the expanded range of brightness values is recorded on film, the result is an expanded density range. Thus, features in the scene are more easily distinguished because scene contrast is higher. If the slope of the film transfer function is increased (figure 11), the raw data will be recorded over an expanded film density range. This technique is referred to as photo-optical enhancement and has been successfully applied to Landsat data (Lucas, Taranik, and Billingsley, 1977a).

Nonlinear Contrast Enhancement

The concept of a nonlinear contrast enhancement is shown in figure 12. In nonlinear contrast enhancement techniques, an algorithm which

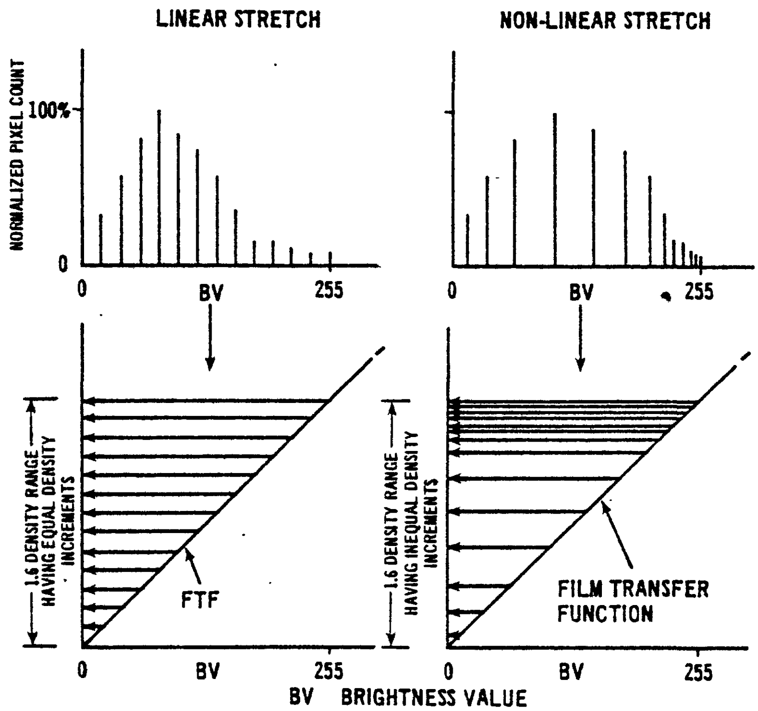


Figure 12.--Concept of nonlinear contrast enhancement. PAO Number: E-6218-35.

redistributes data values is applied to the original data in a manner such that increments of scene brightness are inequally distributed over a range of 0 - 255. Some nonlinear contrast enhancement algorithms that are employed are the following:

1. Piecewise-linear
2. Ramp cumulative-distribution function
3. Probability distribution function
4. Sinusoidal
5. Gaussian
6. Power, logarithmic

As an example, the probability distribution function stretch spreads brightness values having the highest frequency of occurrence farthest apart and it compresses those values having the lowest frequency of occurrence. The nonlinear stretch shown in figure 12 is a probability distribution stretch. Nonlinear contrast enhancements can be extremely useful in the analysis and interpretation of imagery for geologic applications. In areas dominated by rock and soil cover for instance, the probability distribution function stretch can make subtle differences in rock and soil brightness more apparent, but at the expense of differences in brightness between playas and clouds and between basalt and water. The use of nonlinear contrast enhancement is restricted by the type and application of Landsat data in the scene. Good judgment by the analyst and several iterations through the computer are usually required to produce the desired result. For these reasons, nonlinear contrast enhancements were not options on EDIES products. When this type of ehancement is desired, it should be performed on an interactive analysis system.

EDGE ENHANCEMENT

Unenhanced Landsat data often has subtle brightness variations which are difficult to detect. These brightness variations are often related to variations in the illumination of topography. Landforms and drainage are expressed by topographic relief. Edge enhancements are used to enhance radiometric patterns which have a certain spatial frequency in the image. When a low frequency filter is employed to enhance a drainage network, only major tributaries will be enhanced (figure 13). A low

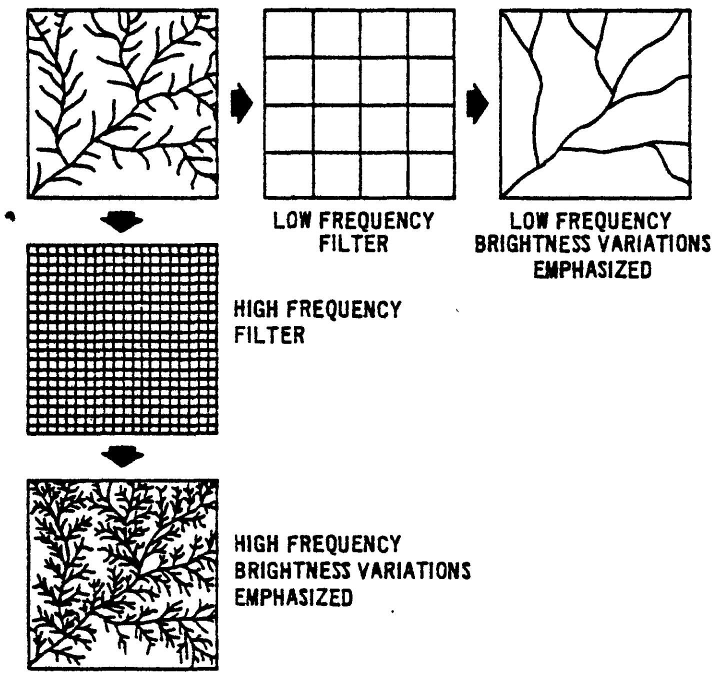


Figure 13.--Concept of spatial frequency enhancement. PAO Number: E-6219-35.

frequency filter examines the average brightness value of a large number of picture elements surrounding the picture element to be enhanced (made brighter or darker). A high frequency filter examines the average brightness value of a small number of picture elements surrounding the picture element to be enhanced (figure 13). After the filter has been applied to the data the new brightness values are applied to appropriate pixels in the image. An example of an edge enhancement is the option that was used by the EROS Data Center to produce EDIES products. Edge enhancement was done by moving a directional filter along each line of data and examining one pixel at a time with a pixel window. A local average of the five pixels on either side of the pixel being examined was used to determine whether the pixel should remain the same or should be enhanced in brightness. Pixels brighter than the local average were made brighter and pixels darker than the local average were made darker. Equation 4 shows how new values were computed for the edge enhancement performed on EDIES images.

$$DN_O = 2DN_I - A$$

where: DN_O = Enhanced brightness value of pixel (output)

DN_I = Brightness value of pixel on CCT (input)

A = Local average from 10 pixels around pixel being examined for enhancement (4)

This edge enhancement technique has the effect of producing a sharper image, but it may introduce artifacts into the data by producing shadows adjacent to features which have abrupt changes in brightness values. Enhancement of drainage and landforms for geologic applications works best in areas of uniform cover. This technique can be considered an estimate of a film modulation transfer function correction if the size is kept small and all directions are weighted equally (Chavez, 1975).

RATIO ENHANCEMENTS

Single Scene Spectral Band Ratioing

The concept of spectral band ratioing is shown in figure 14. A

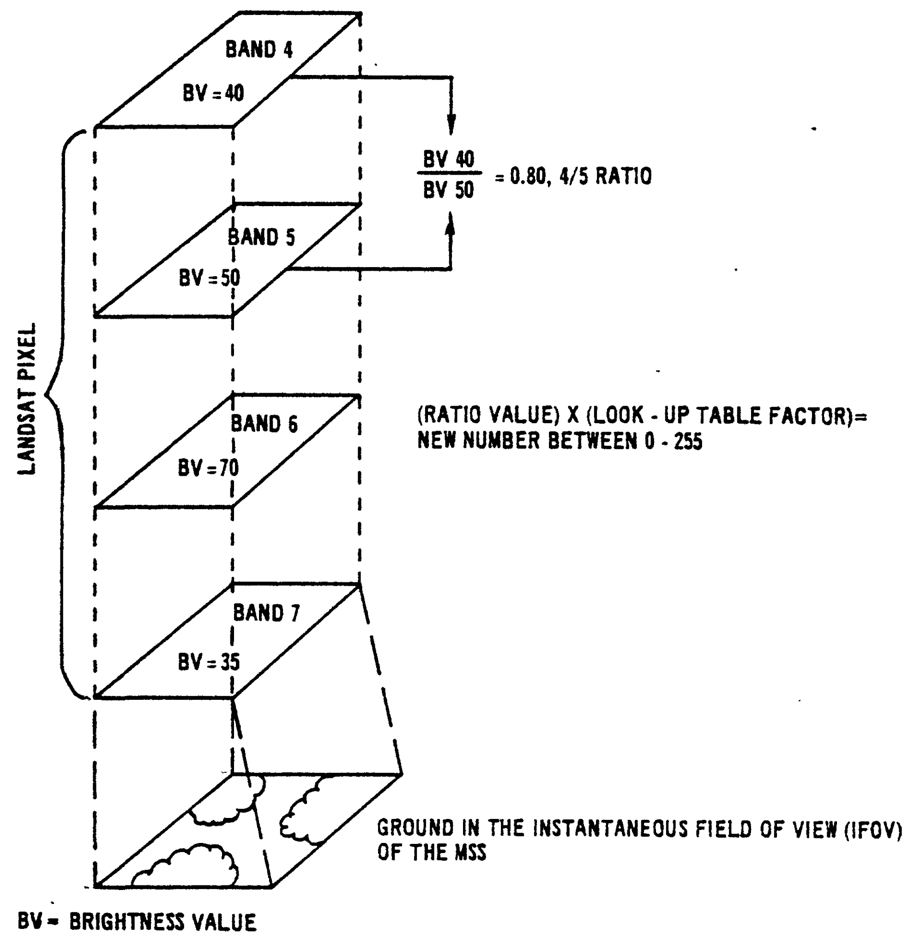
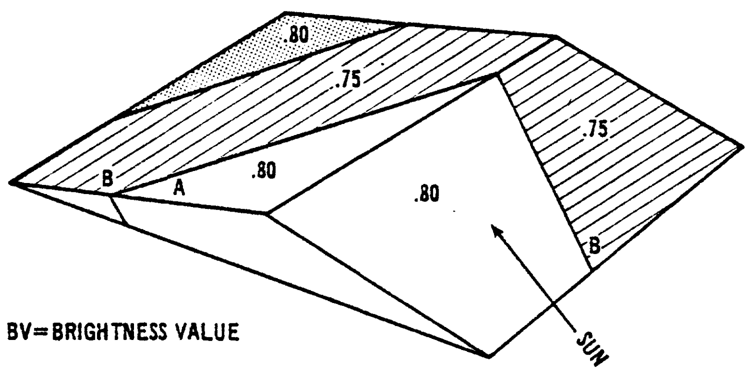


Figure 14.--Concept of spectral band ratioing. PAO Number: E-6220-35.

ratio of two Landsat bands is obtained by dividing the brightness value in one band by the brightness value in another band for each picture element within the scene. The ratioed values are usually multiplied by a factor from a look-up table so that all values will lie between 0 and 255. If Landsat data are not corrected for atmospheric effects, the most practical band ratios are obtained by dividing the brightness values of band 4 by two times the brightness values of band 5 (4 ÷ 2x5), the brightness values of band 5 divided by two times those of band 6 (5 ÷ 2x6) and the brightness values of band 6 divided by two times band 7 (6 ÷ 2x7) (Chavez, personal communication). The rationale for ratioing is shown in figure 15. Even though the two slopes receive a different flux



	BAND 4 (BV)	BAND (BV)	4/5 BAND RATIO
SLOPE FACING SUN			
UNIT A	20	25	.80
UNIT B	30	40	.75
SLOPE FACING AWAY FROM SUN			
UNIT A	15	20	.80
UNIT B	24	32	.75
UNIT C	32	40	.80

ATMOSPHERIC RAYLEIGH SCATTER ADJUSTMENT APPLIED TO DATA

Figure 15.--Rationale for ratioing. PAO Number: E-6221-35.

of electromagnetic radiation from the Sun, and even though the same materials have different brightness values on the opposed slopes, the ratios of the brightness values will be the same on either slope if the data have been adjusted for atmospheric effects. Ratioing tends to reduce the effects due to topography and to emphasize the changes in brightness values between materials (Chavez, 1975).

Single Scene Hybrid Spectral Band Ratioing

Note on figure 15 that if unit C were adjacent to unit A, the two units could not be distinguished from one another by a band ratio, even though they were on the same slope and had different brightness values. This problem can be overcome by combining a single Landsat band with one or more of the ratioed bands. However, care must be taken so topography does not greatly influence colors produced on imagery. Some color combinations useful in displaying ratios of Landsat spectral band and band ratio combinations are shown in figure 16.

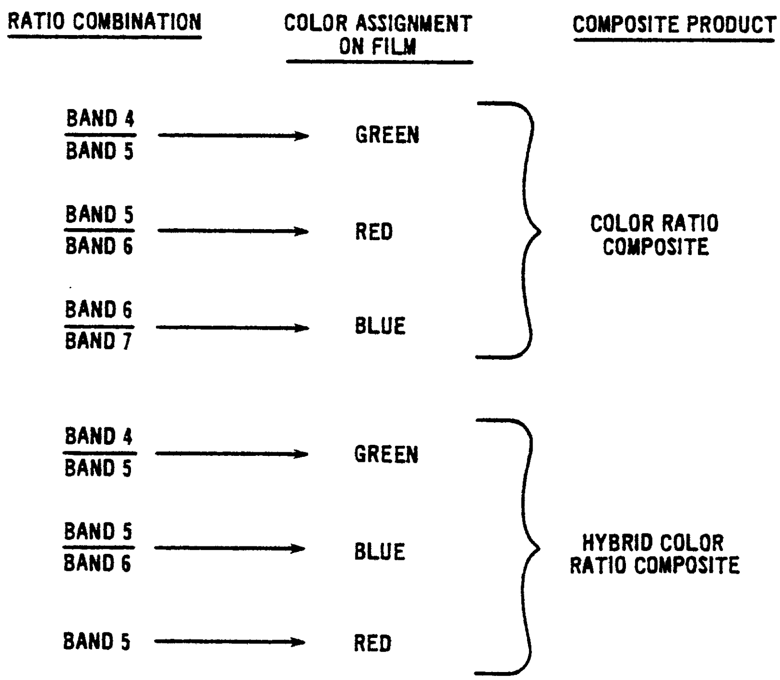


Figure 16.--Color combinations for ratio spectral band or band ratio combinations in Goldfield, Nevada. Other combinations can be used, depending on what is most appealing to the analyst. PAO Number: E-6222-35.

TEMPORAL RATIOING

One useful technique for determining changes in landscape cover conditions with time is to form a temporal ratio of the same Landsat band. For example, strip mine development in Pocatello, Idaho, was monitored using a ratio of two band 5 images acquired two years apart (Carneggie and Holm, 1976). On band 5 a high contrast exists between bare ground and vegetation. On the temporal ratio new areas of bare ground appeared as bright areas. In areas where no change had taken place the ratio image had a uniform gray tone. Good results have been achieved by differencing ratios in two scenes of Phoenix, Arizona. Ratioing before differencing, suppresses topographic and Sun illumination problems and only brightness or albedo differences due to cover changes are shown (Chavez, Berlin, and Mitchell, 1977).

SIMULATED NATURAL COLOR ENHANCEMENTS

The Center for Astrogeology in Flagstaff, Arizona, has developed a technique for displaying colors on Landsat imagery as they would appear to a human observer with normal color vision. The Earth's surface is displayed in color as if the Earth lacked an atmosphere and the observer is at orbital altitude. These types of images are often called "natural" color images as opposed to the "false" color images for standard Landsat products. Because Landsats-1 and-2 do not record a blue visible band, standard Landsat color products are printed so that the green visible band (band 4) is blue, the red visible band (band 5) is green, and the invisible infrared band (band 7) is red. Simulated natural color images are developed from a computer produced blue band. This blue band is displayed as visible blue, the existing Landsat band 4 (visible green) is displayed as visible green, and the existing Landsat band 5 (visible red) is displayed as visible red on simulated natural color images. A schematic diagram illustrating how simulated color production is accomplished is shown in figure 17. Raw Landsat data is corrected for

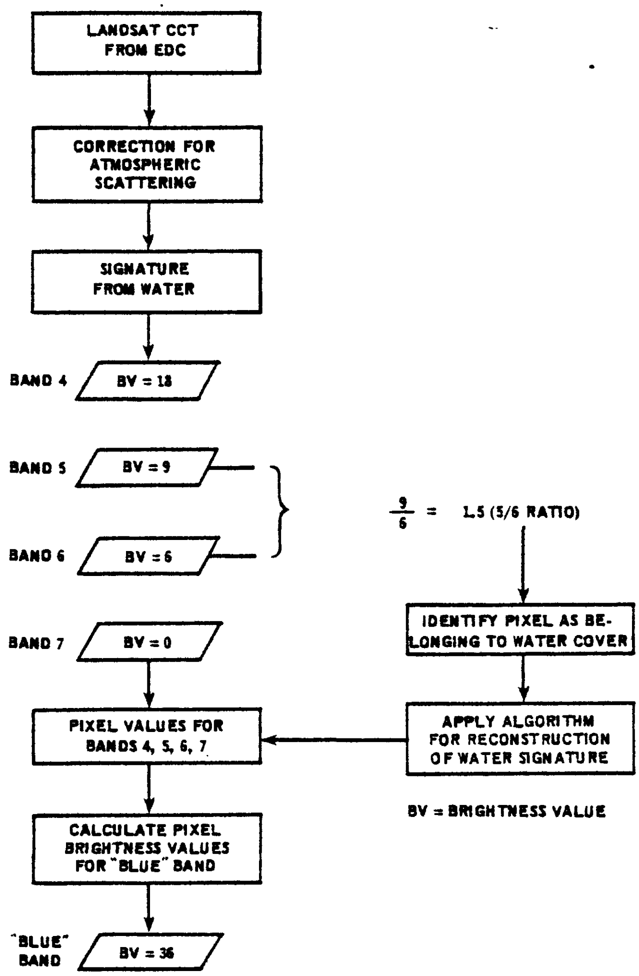


Figure 17.--Simulation of natural color at the U.S. Geological Survey facility in Flagstaff, Arizona. PAO Number: E-6223-35.

atmospheric scattering. Then a 5/6 band ratio is used to identify pixels as belonging to soil-rock (ratio value of 1.5), vegetation (ratio value of 0.45), or water classes (ratio value of 1.45). An algorithm is then applied to the data in all spectral bands to determine the brightness for pixels in the new "blue band" (figure 18). This technique is

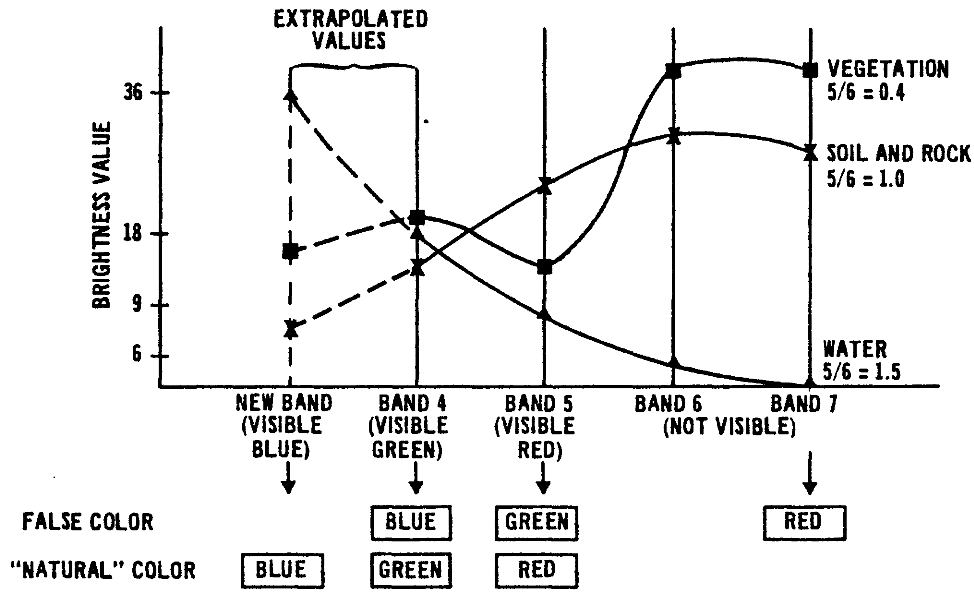


Figure 18.--Concept of natural color simulation. PAO Number: E-6224-35.

fully explained in Chavez, Berlin, and Mitchell, 1977.

The U.S. Geological Survey's Telegeology processing facility located in Flagstaff, Arizona has produced a simulated natural color electronic mosaic of Nevada from 32 Landsat scenes. The mosaic was produced from computer tapes by the procedure shown in figure 19. The data were compressed (sampled) to be compatible with the film recorder resolution. Adjustments to pixel brightness values for scenes having different illumination conditions and atmospheric effects were applied to make the

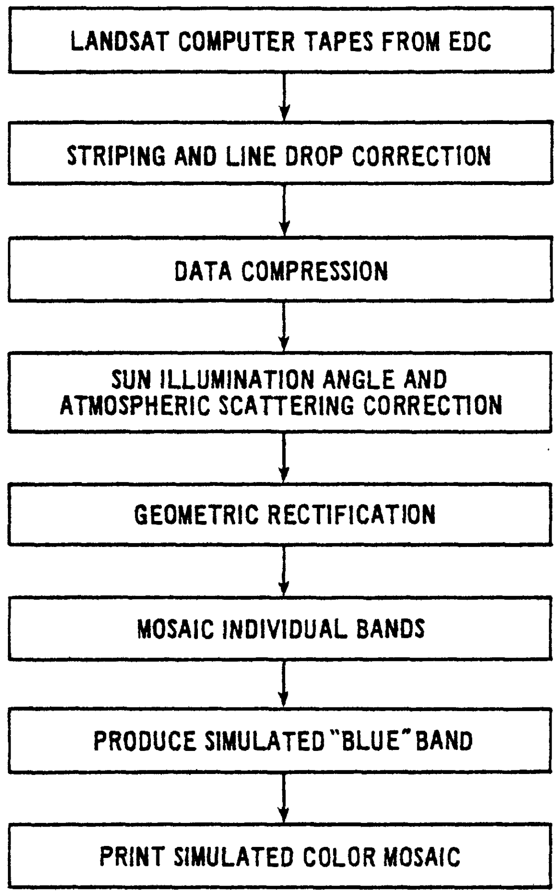


Figure 19.--Development of a computer generated mosaic of Nevada. Shows some of the processing steps used by the U.S. Geological Survey in Flagstaff in producing a simulated natural color mosaic from more than 32 Landsat scenes. Final master transparency measures 125 mm by 250 mm.

data appear as if it were acquired under uniform solar illumination and atmosphere. After the data were geometrically rectified, the data from individual Landsat bands were computer mosaicked. Then brightness values for a simulated "blue band" were determined using the approach previously described. Finally the mosaic was composited in color by printing the "blue band," green band (band 4), and red band (band 5) using blue, green, and red light respectively (figure 18).

Simulated natural color imagery is produced for the U.S. Geological Survey's personnel for use in regional geologic mapping, particularly in arid environments and in Alaska. For example, on false color images (standard products), red rocks appear yellow-green. On simulated natural color images such rocks would appear red, more like geologists would see them in the field.

IMAGE CLASSIFICATION

Image classification of Landsat-1 and-2 data involves both machine assisted delineation of multispectral patterns in up to four dimensional spectral space and identification of machine delineated multispectral patterns that represent landscape cover patterns. The first process is called multispectral analysis and the second process is called multispectral classification (figure 1). Image data are not classified until an interpreter determines which spectral classes are representative of particular cover conditions. A geologist must then determine the relationships between cover classes displayed by the multispectral classification and the geology. Most geological information derived from an analysis of a multispectral classification is related to lithology (figure 1).

If an algorithm is employed to determine "natural" groupings of multispectral data in four dimensional spectral space, then the image is said to have been analyzed using an unsupervised approach. The clustering analytical processor described by Anuta (1977, p. 425) is a good example of this approach. If the analyst "trains" the analytical processor by selecting samples of classes to be recognized, then the image is said to have been analyzed using a supervised approach (figure 20). The maximum likelihood analytical processor described by

TYPES OF CLASSIFICATION TRAINING

- UNSUPERVISED – IDENTIFICATION OF NATURAL CLUSTERS OF DATA IN FOUR SPECTRAL DIMENSIONS USING ALGORITHMS

- SUPERVISED – DETERMINATION OF THE SPECTRAL LIMITS OF A SPECIFIED NUMBER COVER CLASSES THROUGH ANALYSIS OF SAMPLES OF THE CLASSES

SOME CLASSIFICATION ALGORITHMS COMMONLY EMPLOYED

- PARALLELEPIPED – DETERMINES WHICH PICTURE ELEMENTS FALL INSIDE A CLASSIFICATION SPACE DEFINED BY THE FOUR DIMENSIONAL SPECTRAL LIMITS OF A PARTICULAR COVER CLASS

- MAXIMUM LIKELIHOOD – DETERMINES WHICH PICTURE ELEMENTS MOST LIKELY BELONG A SPECIFIED CLASS FROM ANALYSIS OF THE VECTOR MEANS AND COVARIANCE MATRICES OF SAMPLES OF ALL CLASSES

Figure 20.--Common procedures used in image classification. PAO Number: E-6226-35.

Anuta, (1977, p. 425) is normally used in a supervised mode.

The parallelepiped classification algorithm employed on the interactive multispectral analysis system at EDC is an example of a multispectral analytical processor used in a supervised approach. An analyst trains the computer on the multispectral limits (in four spectral dimensions) by positioning an electronic cursor over a particular cover type on a television screen. The computer determines the minimum and maximum brightness values within the training area for that cover type in four Landsat bands. The computer searches each pixel in the entire scene and determines which picture elements have brightness values that fall within the maxima and minima for the training area. The picture elements which occur within the restricted ranges of brightness of the training area are classified and identified by a color code on imagery or letter code on a print-out. The concept of the parallelepiped classification algorithm is shown in figure 21. For purposes of illustration only three spectral

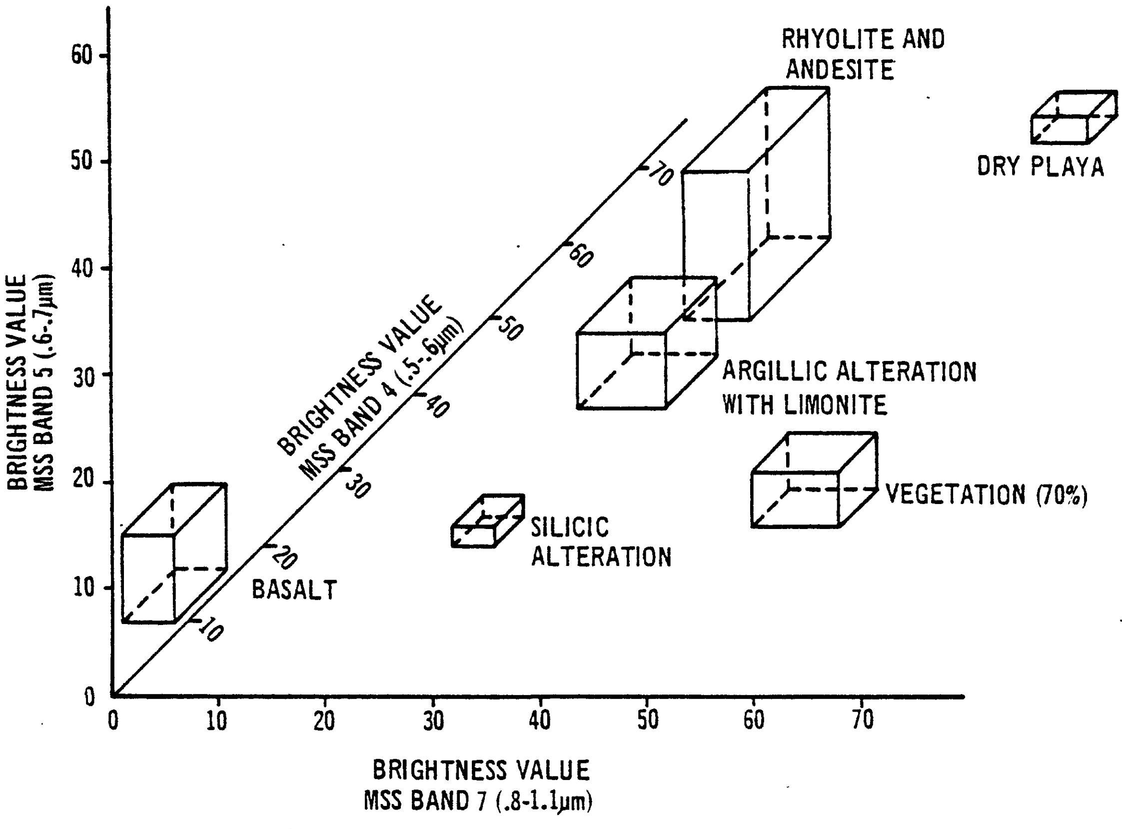


Figure 21.--Concept of parallelepiped classification algorithm. PAO Number: E-6431-35.

band axes are shown in figure 21.

Image classification techniques have been little used for geologic applications compared to enhancement techniques. The relationships outlined in figure 1 partially explain why the classification approach has been little used in analyzing data for mineral and petroleum exploration.

The classification approach provides mostly information on cover conditions, and a geologist must interpret the lithologic significance of the classification before it can be used as part of an analysis of potential targets for exploration. The integration of spectral response by the MSS is shown in figure 22. The difficulty in using image classification

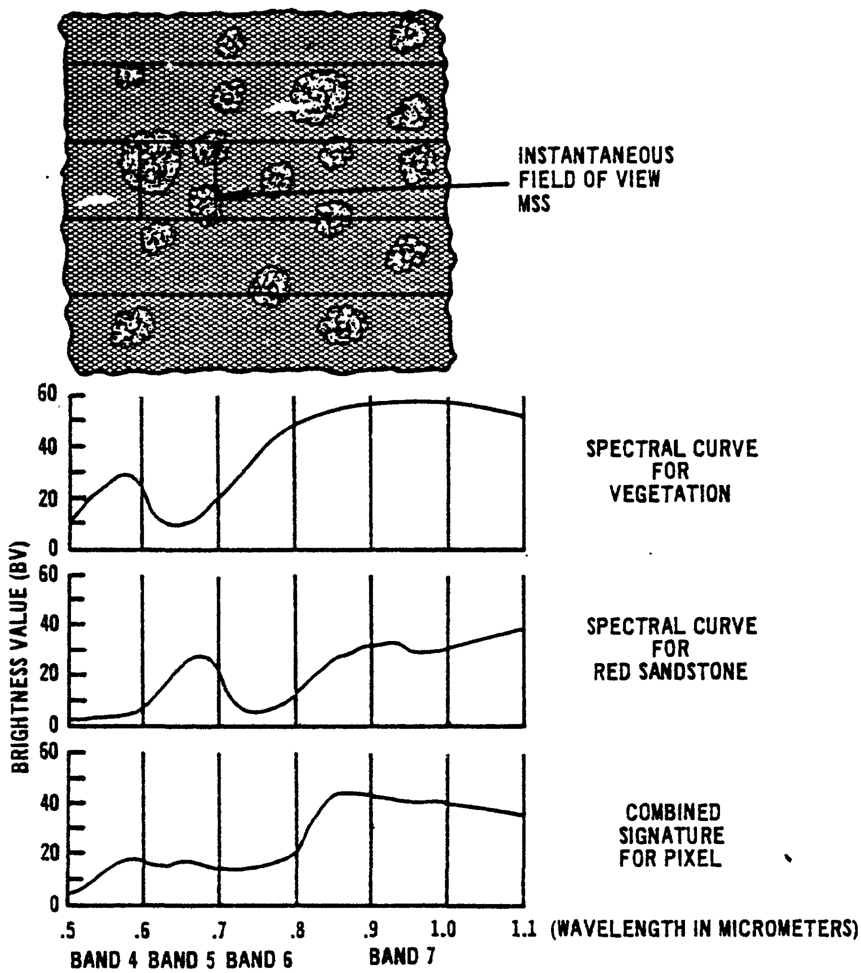


Figure 22.--Integration of spectral response by the Landsat MSS. Atmospheric effects ignored. PAO Number: E-6192-35.

techniques for geologic studies is compounded by effect of the atmosphere on spectral brightness values measured by the MSS (see figure 23).

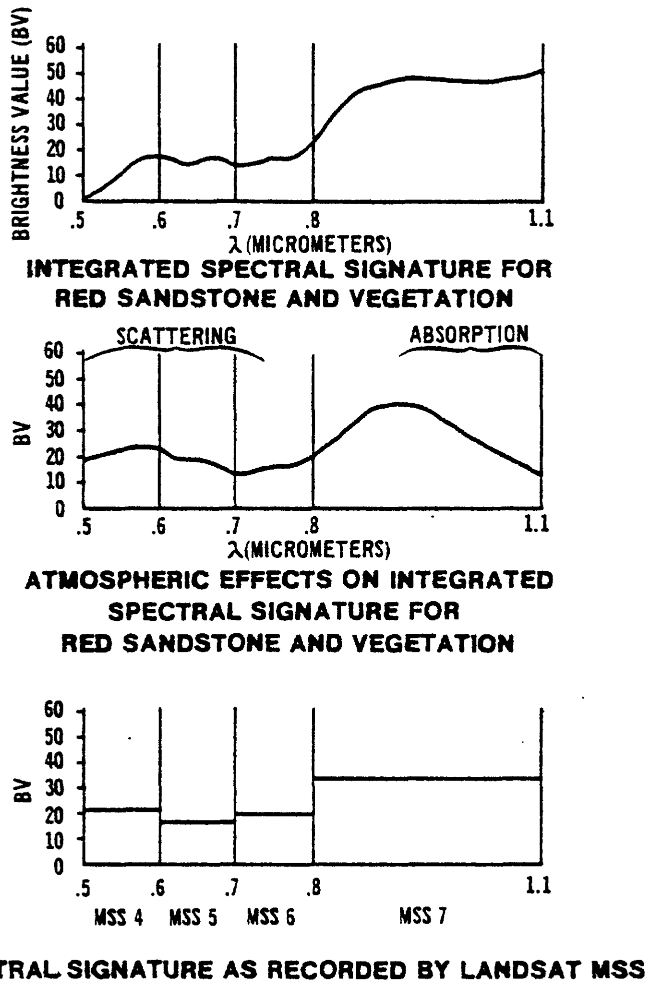


Figure 23.--Atmospheric effects on spectral signature recorded by the Landsat MSS. PAO Number: E-6193-35.

It is absurd to expect that image classification techniques can be used to replicate geology mapped at large scales. The natural surface of the Earth is composed of a diversified combination of cover types, and rarely are unweathered, bare rock materials exposed at the surface. Many consolidated rocks at the surface are altered by chemical and biological agents, are covered by unconsolidated rock materials, contain or are covered by water, or have soils mantling them. Lichens may coat bare rocks; grasses, shrubs, and trees obscure the soils on which they have developed. Man often obliterates natural surface cover and, in its place, erects structures or plants crops. The ground-based geologist maps geological units by (1) interpolating between rock exposures, (2) using rock fragments exposed in soils, (3) using residual soil associations, (4) using plant associations, and (5) projecting geometric attitudes of exposed rock strata into areas dominated by other cover types (Taranik and Trautwein, 1977, p. 774). In spite of this the combination of plant, soil, and water associations with geologic units, and sometimes the unique spectral characteristics of lithologic relationships do permit classification procedures to be successfully applied to Landsat data for targeting of ground-based geologic investigations. Successful application of the classification approach requires a thorough understanding of the remote sensing system, the machine analysis procedures involved, and an appreciation of what cover conditions are being displayed by the multispectral classification.

For additional reference materials on the use of the Landsat system for mineral and petroleum exploration, the user of this material should consult Taranik, (1978).

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