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PRINCIPLES AND PRACTICES OF SATELLITE MULTISPECTRAL IMAGE MAPPING IN THE U.S. GEOLOGICAL SURVEY

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PREFACE

In support of the U.S. Geological Survey's (USGS) mission to provide leadership in the development and advancement of mapping technology, the National Mapping Division has been in the forefront of image mapping research and development. Since the first USGS publication of image maps over 15 years ago, image mapping has progressed with new innovative methods making possible the retention of greater resolution and color purity. The methods discussed here focus on techniques for radiometric and geometric correction, image enhancement, tape-to-film transformation, color separation, and printing.

With the advent of new computer processing techniques for image mapping, digital data from Landsat sensors have shown to be more effective in producing geometrically corrected images on film and in generating publication-scale film separates for color printing. Continued research and development in computer-aided image mapping is expected to significantly reduce costs and improve the quality of future image map products.

There are numerous technical articles written on digital image processing but few link the processing with the production of color image maps. Both digital image processing and lithographic printing are complex and highly technical subjects. This paper will give a conceptual understanding of image map principles and practices of multispectral image mapping at the U.S. Geological Survey. Past experimental image map projects performed by the USGS with Landsat multispectral digital data, including the Saudi Arabia MSS Image Map Series and more recent Thematic Mapper Image Maps of selected regions of the United States, have formed the principles on which color image map development are built and are primary source material for this paper.

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CONVERSION TABLE

U.S. metric units used in this paper may be expressed as U.S. customary units by the use of the following conversion factors:

Multiply	By	To Obtain
meters	3.281	feet
kilometers	0.6214	statute miles

U.S. customary units used in this paper may be expressed as metric units by the use of the following conversion factors:

Multiply	By	To Obtain
feet	0.3048	meters
statute miles	1.609	kilometers

ABBREVIATIONS AND ACRONYMS

BV	brightness value
CCT	computer-compatible tape
CT	continuous tone
EMR	electromagnetic radiation
DN	digital number
EDIPS	EROS Data Center Digital Image Processing System
EROS	Earth Resources Observation System
GSFC	Goddard Space Flight Center
HDT	high-density tape
HRFR	high-resolution (laser beam) film recorder
MSS	Landsat multispectral scanner
NMD	National Mapping Division (USGS)
OIF	optimum index factor
pixel	picture element
TM	Landsat Thematic Mapper
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

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Abstract

The U.S. Geological Survey (USGS) has been involved in research and development of using satellite multispectral data for mapping for over 15 years. Until recently, satellite images have been used primarily as a research tool for the evaluation of earth resources. Their value as "maps" is now being recognized as the result of a successful experimental image map program.

The fundamental principles of the tranformation of digitally processed satellite multispectral images into lithographic printed maps are important to a conceptual understanding of image mapping. Satellite image mapping can be divided into two major phases: (1) the digital processing phase where the images are geometrically and radiometrically corrected, registered to an appropriate map projection, and enhanced to improve image detail and tonal contrast; and (2) the production phase which involves the transformation of the digital image data to generate film separates and its subsequent gray balancing, screening, and enlargement to publication scale in preparation for platemaking and printing.

Since the digital "image" has a greater dynamic range than its photographic analog equivalent, steps are taken during processing to assure that the value range of the digital data is transformed to remain within the value range capability of the lithographic press. The results have produced quality intermediate- and small-scale satellite image maps for the user community.

INTRODUCTION

The general evolution of a color image map from satellite signal transmission to printing can be summarized in figure 1. Preprocessing of the Landsat multispectral image data is performed at the Goddard Space Flight Center (GSFC) image processing facility in Greenbelt, Md. At Goddard, the digital image is partially or fully corrected for geometric and radiometric distortions and recorded on high-density digital tapes (HDT's) for distribution and transfer to computer-compatible tapes (CCT's). The U.S. Geological Survey's image processing facility at EDC (Earth Resources Observation System Data Center) in Sioux Falls, S.Dak., provides most of the digital processing of Landsat images. The first-order processing of the multispectral data of each image is performed on EDC's digital image processing system or EDIPS. EDIPS allows the manipulation of the digital data of any selected image in order to achieve a desirable product (Ragland and Chavez, 1976). Once this is achieved the digital image is printed on film by means of a high resolution laser beam film recorder subsystem (HRFRS), or the McDonald Dettwiler Color 240 Recorder (currently being employed on an experimental basis).

The rest of the processing is completed at the U.S. Geological Survey's mapping and printing facility in Reston, Va. Here the film separates generated from the processed digital data of each spectral band or channel are reexamined, primarily for tonal balance and lithographic compatibility. Necessary tone adjustments, neutral balance, halftone screening, and scale enlargements are rendered on a computer-controlled scanner/plotter to produce three screened separates at the final scale. After inspection and approval of a color proof, the final separates are assembled and reproduced with a fourth separate containing black line/type as contact negatives. This step is then followed by platemaking and lithographic printing to generate the final image map product.

IMAGE MAP DEVELOPMENT

The Computer-Generated Digital Image

There are two basic types of information that may be derived from satellite image data digitally recorded on a magnetic tape. The first is the location of a picture element (pixel) which is derived from its respective location on a grid or array of pixels, and second is the amplitude of the ground radiance of the area being sensed (see fig. 2). Pixel arrays generally consist of sequentially numbered rows and columns. The rows are commonly referred to as lines and the columns as samples. The location of a pixel within the pixel array is defined with respect to its line and sample position, and the pixel's value is defined with respect to the digital number (DN) assigned to it. The radiance amplitude of the ground area being sensed is mapped into a DN value range. This DN is based on the level of electromagnetic radiation reflected by the area being imaged. These DN values translate into discrete gray levels on the image. Generally, the range of DN's or brightness values is from 0 to 255, where 0 value represents no radiation or reflectance detected (black) and 255 represents the maximum radiation (white). Multispectral scanner (MSS) images are

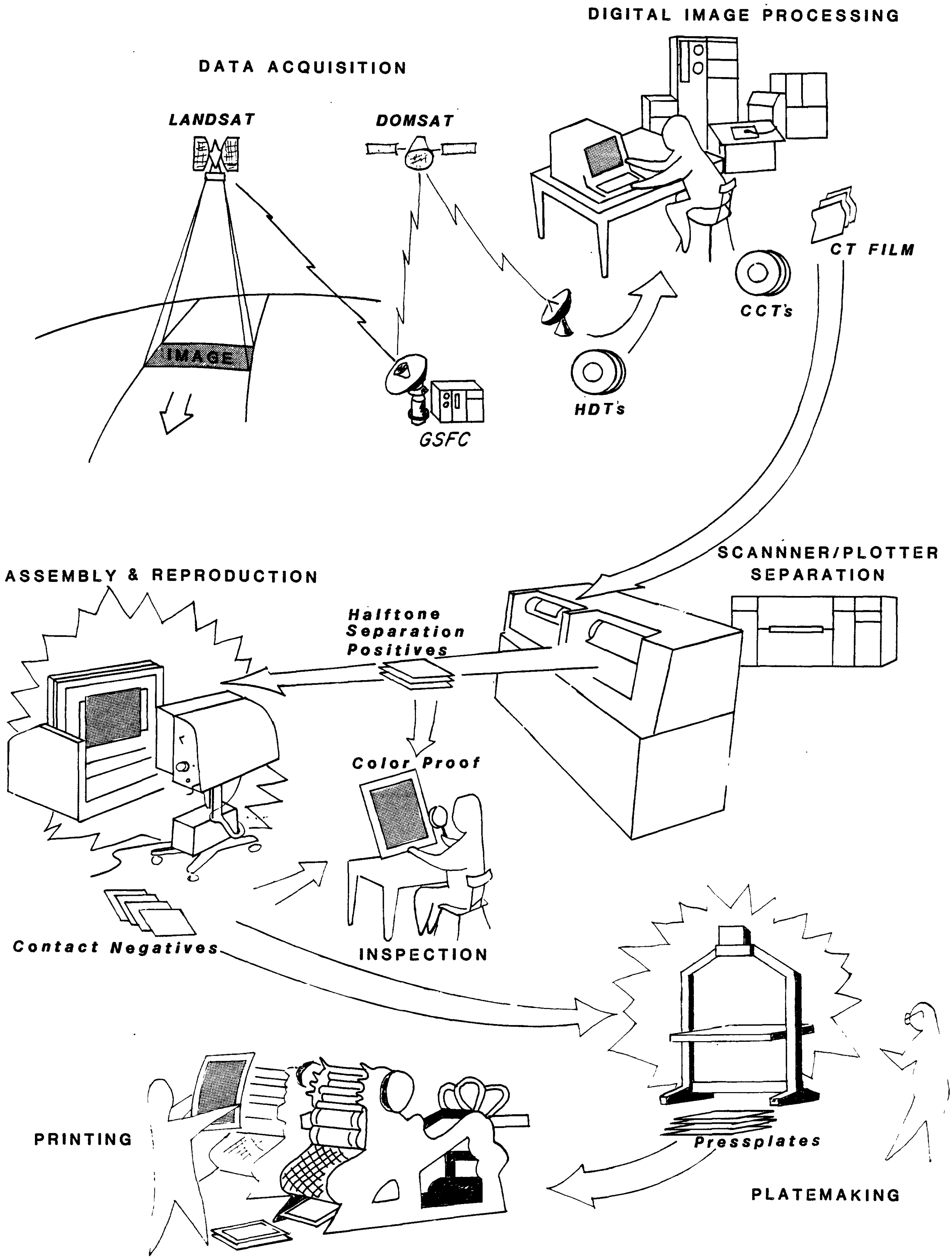


Figure 1. The satellite image mapping process.

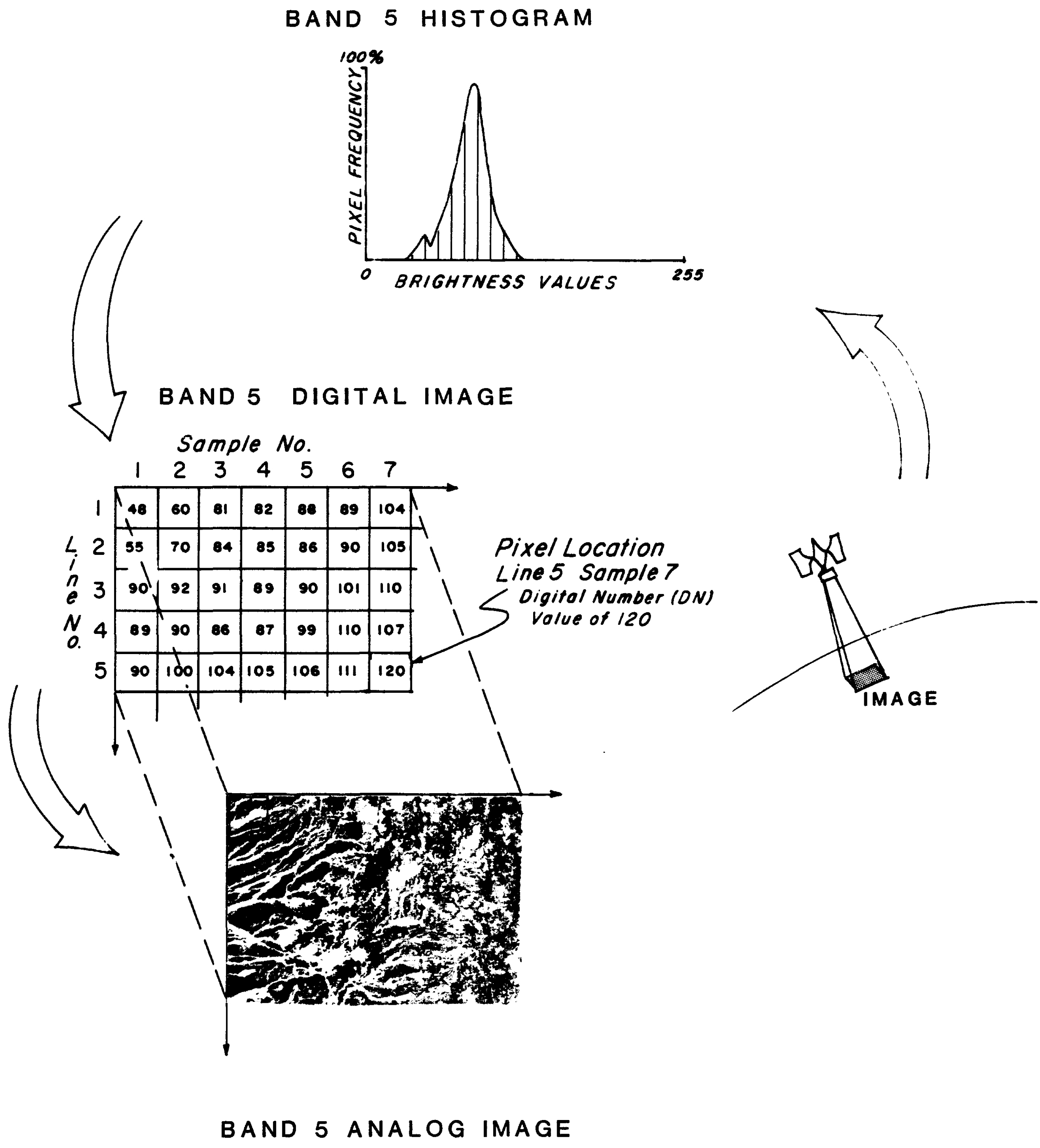


Figure 2. The relationship between pixel brightness values (gray levels) on a hard copy with digital numbers of a multispectral scanned image.

recorded in 64 brightness levels, while the images of the second of the two Landsat multispectral sensor system, the Thematic Mapper (TM), are recorded in 256 brightness levels.

One Landsat MSS scene covers approximately 185 x 185 kms or 34,225 sq kms of the Earth's surface. This MSS scene consists of a pixel array of about 3,240 samples by 2,340 lines for each of the four MSS bands, or approximately 7.6 million pixels total. Each MSS pixel represents a 57 x 79 meter area. Due to an aspect-ratio distortion in the across-track versus along-track direction, pixels are elongated rather than square. This causes features to be stretched. To geometrically correct this pixel distortion, the image must be transformed to square pixels (representing 57 meters square on EDIPS).

Six spectral bands of the Thematic Mapper (TM) sensor on board Landsats 4 and 5 have a pixel size of approximately 30 meters square; thermal band 6 has a pixel size of approximately 120 meters square. The TM generates approximately 300 million pixels per scene. The pixel array for a TM image is approximately 6,800 samples by 6,500 lines, representing 30,525 sq kms of the Earth's surface (185 km x 165 km).

The multispectral bands of the MSS and TM Landsat series sense electromagnetic energy (EME) reflected from the earth at combined optical and infrared wavelengths of 0.5 to 1.1 um and 0.45 to 2.35 um, respectively (TM Band 6, 10.4-12.5). A period on this page is about 0.6 mm in diameter, or about 857 wavelengths of red light in diameter. See table below for precise coverage.

Table 1. Landsat Wavelengths
by Class, Magnitude, Color and Band

Wavelength		Light	Bands		Wavelength (um)	
Classes	Magnitude(um)	Color	MSS	TM	MSS	TM
Visible	0.4 - 0.5	Blue		1		0.45 - 0.52
Visible	0.5 - 0.6	Green	4	2	0.5 - 0.6	0.52 - 0.60
Visible	0.6 - 0.725	Red	5	3	0.6 - 0.7	0.63 - 0.69
NearIR	0.725 - 1.1		6	4	0.7 - 0.8	0.76 - 0.90
	"		7		0.8 - 1.1	
MidIR	1.1 - 5.5			5		1.55 - 1.75
	"			7		2.08 - 2.35
FarIR	5.5 - 15.0			6		10.40 -12.50

Data Correction

Corrective restoration of Landsat digital data is necessary to remove distortions introduced by the sensor system, atmosphere, Sun angle, and irregular topography. Various correction techniques have been designed to adjust for radiometric and geometric defects. One must keep in mind that when correcting for image distortions, some alteration of the original data does occur, and these alterations may cause some changes in information. However, the data correction techniques are designed so that the corrected image will be easier to interpret than the original. Certain fundamental correction techniques are used most often in the correction of Landsat multispectral data for image mapping.

Radiometric Restoration

Detector Correction. Calibration of the output of Landsat's MSS or TM detectors (6 and 16 per band, respectively) is necessary to correct for the visible horizontal stripes or banding that is caused by the differences in the output digital numbers that the detector's generates for the same target brightness.

A widely use correction technique is to compile histograms of each detector's scan lines over a large number of data samples. The objective is to measure the differences in the outputs of the detectors in each band. The measurements are then used to adjust the data from each detector so that the resultant histograms are normalized or averaged. This technique has proven successful in removing most of the striping by producing identical responses for all detectors in each of the bands.

Another approach is to use convolution filtering, which uses an averaging technique to correct for the striping. While convolution filtering has been found to be more complete in removing striping, it does not preserve the overall radiometry of the image as well as the histogram normalization approach. For more on the spatial and histogram normalization approaches see Chavez, 1975.

Drop Line Correction. Data lost during detection, transmission, processing, etc., are associated with irregular horizontal image patterns or radiance intensity values near saturation of the histogram's edge--these are usually dark horizontal stripes of 1 or 2 lines in width and most of the time have a DN value of about 0 (Chavez, personal communications). One method commonly used to replace a dropped line of data is to replace it with values computed by interpolating between the digital values in the lines above and below the dropped data line.

Another technique, employed by EDC in their Digital Image Enhancement System (EDIES), is to replace the missing digital values with values from the preceding line. This technique is often referred to as pixel duplication (Rohde, Lo, and Pohl, 1978).

Correcting for Atmospheric Effects. Atmospheric scattering and/or water vapor absorption can influence measurably the spectral composition of light reaching the Landsat scanners or detectors. The longer infrared wavelengths (0.725 to 15.0 um) are affected less by atmospheric scattering than are the shorter visible wavelengths (0.4 to 0.725 um), which include the region of MSS bands 4, 5, and 6 and TM bands 1, 2, and 3. The scattering effect in the atmosphere increases the spectral composition of light of the shorter wavelengths so that shadow areas of the digital image have higher brightness values than normal. By comparison, the infrared MSS band 7 and TM bands 4, 5, and 7, often register a zero brightness value in these same areas because no radiation is received on the longer wavelength bands. A haze removal procedure is used to correct for atmospheric effects. This procedure subtracts the lowest digital value from all the pixels in that band, so that the digital value in each band begins at zero ("haze correction program," Chavez, 1975). A simplified illustration below demonstrates the results:

MSS	LOWEST VALUE		HIGHEST VALUE	
BANDS	Before	After	Before	After
4	11	0	59	48
5	7	0	65	58
6	3	0	62	59
7	0	0	29	29

Solar Illumination Correction. Sun angle can accentuate variations in brightness and darkness with an image. A technique normally used to correct for the Sun elevation effect is to multiply the brightness values within a scene by a constant that is derived from dividing the pixel brightness value by the cosine of the Sun elevation angle ("illumination angle program," Chavez, 1975). This normalizes the overall tone or scene brightness to a constant Sun angle while not altering the differences due to topography and spectral reflectance.

Geometric Correction

The geometric errors associated with the data received from Landsat are either along-scan or cross-scan geometric distortions, or a combination of both. Along-scan distortions result from the Earth's rotation, satellite altitude, and mirror velocity. Cross-scan distortions are caused by satellite velocity and scan skew. There are several correction procedures which allow the image to be rectified for geometric errors. Two geometric errors and their correction techniques are described.

Earth Rotation. As Landsat records successive scans the Earth is rotating below. The scans are all aligned as the data are recorded on magnetic tape. It takes approximately 25 seconds to record the 185 km MSS scene and in this time the Earth has rotated to the right relative to latitude. To compensate for this rotation, the bottom or last scan line should be left justified, but the previous scans should be shifted in groups of 6 (due to 6 detectors per band) to the right to compensate for the Earth's rotation. The first scan lines are moved to the right based on the velocity of the Earth at the given latitude and each successive set of scan lines are moved to the right less and less until the last set of scan lines is left justified.

Mirror Velocity Variation. The mirror scanning device of the Landsat imaging system moves at a constant angular rate. The velocity rate of the mirror across the scan will therefore vary when data samples are taken at regular time intervals. This causes differences in the scan line length within a scene. The correction technique normally employed involves the insertions of pixels using a piece-wise linear interpolation method in which the digital values of the inserted pixels are derived by linear interpolation of the digital values of the adjacent pixels.

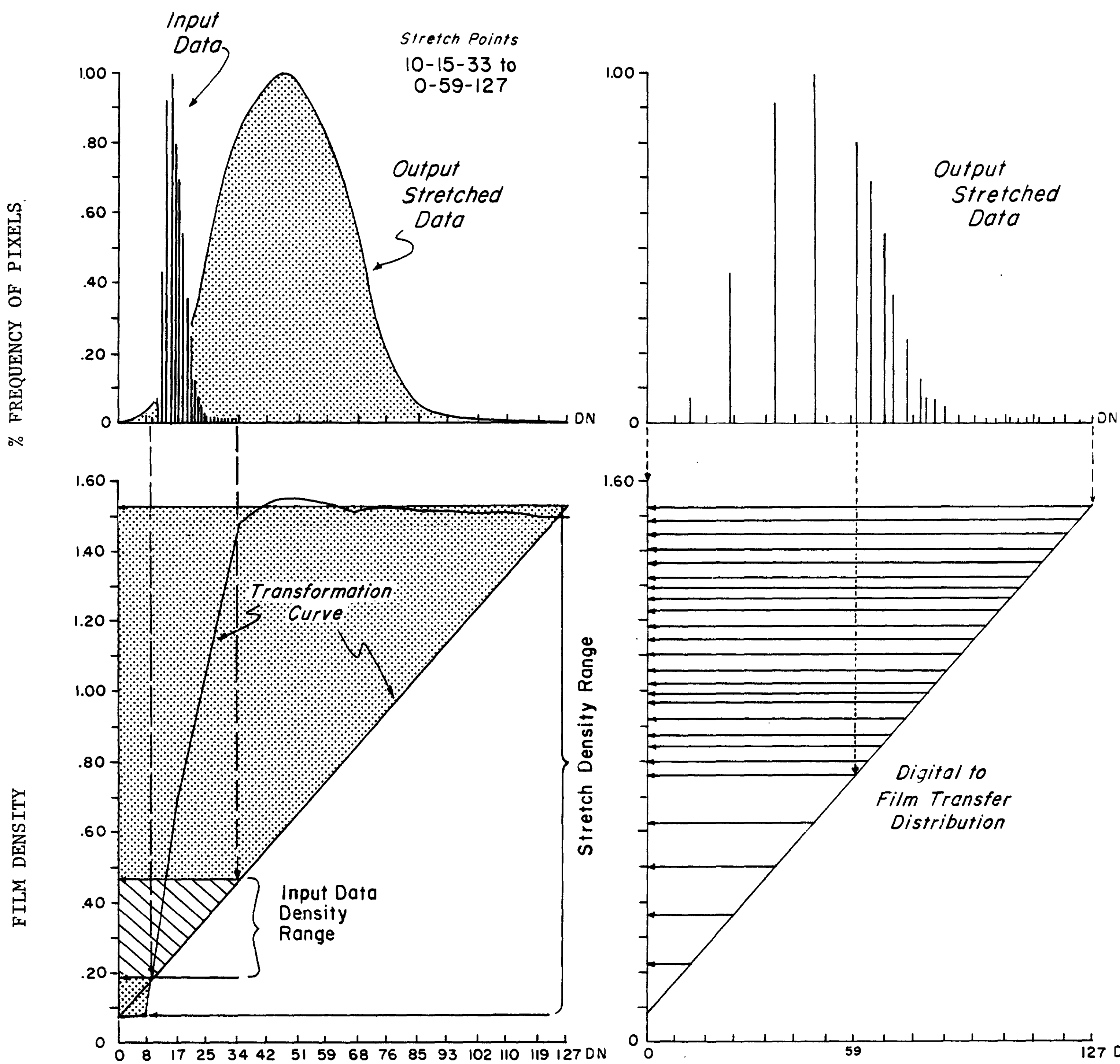
Data Enhancement

The enhancement of a digital image normally involves the selective alterations in contrast or edge accentuation applied to particular features in an image. In order to gain the full benefit of image enhancement, an optimum relationship in density range is necessary between the digitally processed scene and the film recorded image that is to be used to lithographically reproduce the image map. If the density range limitation of the lithographic press are not taken into consideration, a digitally enhanced image cannot be printed at optimal density. The image enhancement technique of contrast stretching is especially critical in obtaining that compatible relationship. Explanations of available data enhancement techniques are covered extensively in other articles (see References). This section will focus on contrast enhancement and spatial filtering (i.e., edge enhancements and add-back filtering), the two most often used techniques in satellite image mapping.

Contrast Enhancement. A digital imaging system can produce more gray levels than can be reproduced on black and white film or differentiated by the human eye, which can resolve up to about 16 distinct shades of gray. Most computer-driven imaging devices work in an 8-bit format, which will display a TM image in 256 discrete gray levels, where black is represented by 0, and white by 255. When an 8-bit format image is recorded on film, the 256 shades of gray contained within the original image data end up being sub-sampled by the human eye at a ratio of 256:16 or 16:1. In figures 3a and b, a sample relationship is shown between the histograms of TM bands 2, 3, and 5 images and their derived film density transformation curves, which begin at 0.08 base fog level. Also provided in figure 3a is the density distribution of the digital-to-film conversion. Without enhancement the narrow range of input image data would be recorded on black and white film as an image with very little contrast (possibly 3 shades of gray).

To enhance contrast and add distinguishable differences in density to the film products, each brightness value of the input digital image must be transformed into a new DN value, and thus film density in the output image. This can be accomplished by using one of several methods of contrast stretch. A linear contrast stretch transforms or maps a selected minimum DN value of the input data to 0, and a selected maximum DN value to 127 (illustration in this paper will often reflect EDC's 7-bit reproduction mode). The intervening DN values are then equally spaced, or linearly distributed, between the two new endpoints.

Figure 3a (top right graph) demonstrates the results of multi-point or piece-wise linear stretch redistribution of the input data. Here the input minimum DN value of 10 is set at 0, the DN middle point value of 15 to 59, and the maximum DN value of 33 to 127. The intervening DN values are linearly distributed over the available DN range between the fixed output points. The digital to film transfer in figure 3a (bottom right graph) illustrates the relationship between the spaced increments of the image's input DN values and the film's output densities which are in linear increments. Keeping in mind that the film density graphs (D log E) of figures 3a and b are



DN	0	8	17	25	34	42	51	59	68	76	85	93	102	110	119	127
GREY SCALE	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Input Density Curve	.08	.08	.70	1.10	1.47	1.54	1.55	1.53	1.52	1.52	1.52	1.52	1.52	1.50	1.50	1.50
Output Density Curve	.08	.17	.28	.38	.43	.56	.66	.75	.86	.95	1.05	1.14	1.24	1.34	1.44	1.53

Figure 3a. Histogram and derived film density transformation curves and distribution of input and output stretched data of band 2, Dyersburg TM Landsat image map. (The digital range used here is based on 7-bit data to show the EDC relationship, so max. DN value = 127.)

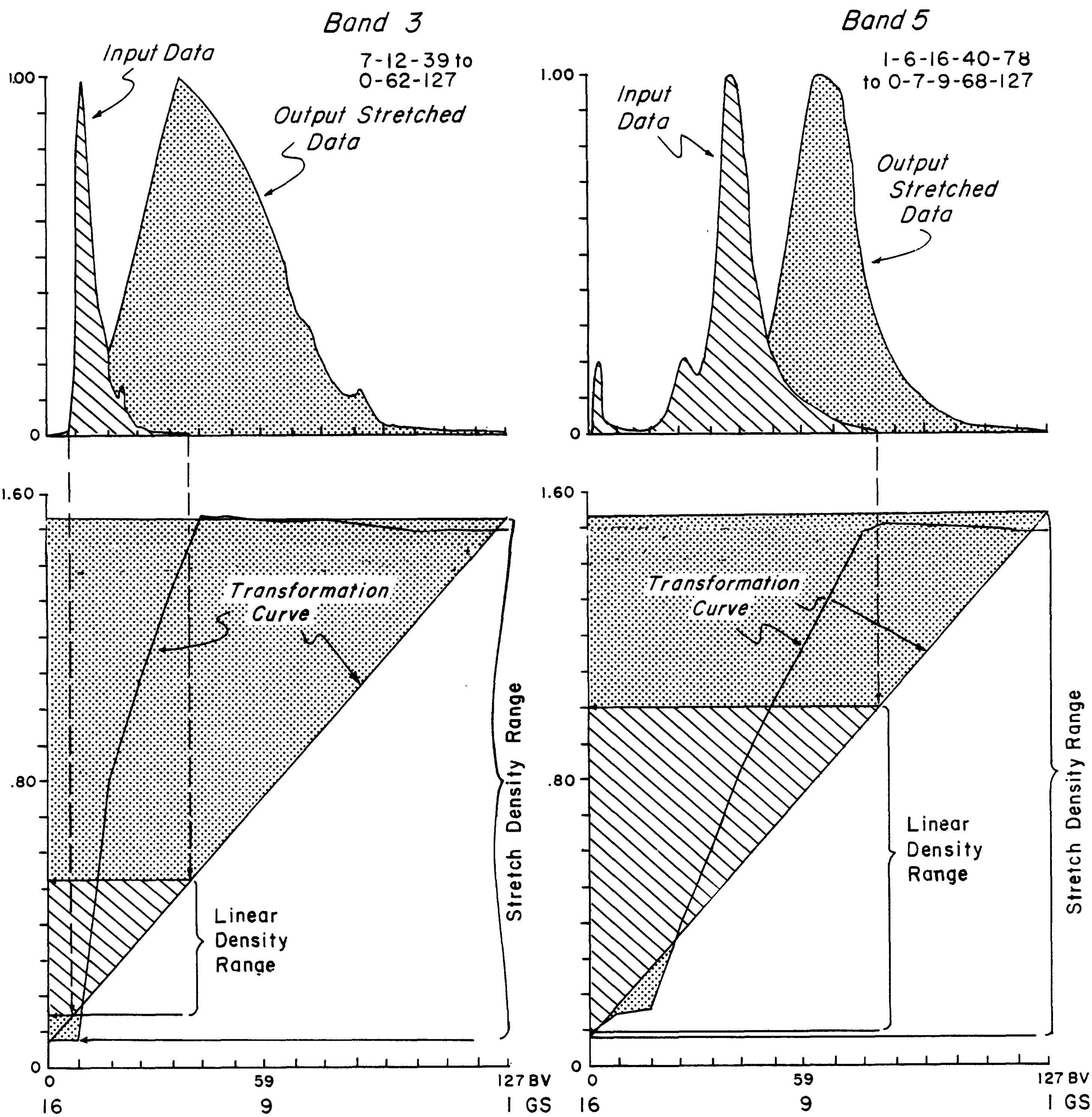


Figure 3b. Histogram and derived film density transformation curves of input and output stretched data for bands 3 and 5, Dyersburg TM Landsat image map (USGS, 1984).

continuous-tone negative (i.e., shadow is read at opposite end of the density scale) one can see that the tone contrast of the image scene will be greater in the shadow areas than in the highlight areas because of the greater spacing between the DN value range from 0 to 59. The mid-tones of the image have less gray level separation. However, overall scene contrast should be improved over the original image. Generally, a linear piecewise or multi-point contrast stretch tends to provide better control over density and differential enhancement of the image than does a total linear contrast stretch. This approach can accentuate subtle differences in selected features on an image, but often at the expense of detail in other features.

Because of the variability of image data, certain characteristics of the frequency histogram should be analyzed to achieve the optimal stretch for any particular image. Some of these characteristics include shape, symmetry, skewness of the DN distribution or gray level, and the modes of the DN values.

Two other contrast enhancement techniques are automatic and histogram-equalization stretches. In the auto-stretch technique, the DN values of a pre-selected high and low percentage of the histogram distribution are saturated or mapped to 0 and 255, respectively. This is usually done using a linear contrast stretch. In the histogram-equalization technique, a stretch is selected that will make the output image histogram as flat as possible. Discussion on the important relationship of the contrast stretch operations and the film density calibration procedure for the reproduction and printing of the image map is addressed later (see "Tape-to-film Calibration").

Spatial Filtering. Spatial filtering can be used to soften or sharpen particular features in an image, such as roads and shadows. In filtering, the DN value for a pixel is changed as a function of the DN values of neighboring pixels (Chavez and Bauer, 1982). A low-frequency (low-pass) filter, which softens or smooths most features of an image, assigns the average DN value of a selected neighborhood of pixels to the center pixel. In doing this the new image is digitally smoothed and high-frequency detail is suppressed, resulting in the "softening" of the definition of particular features due to the defocusing effect. In contrast, an image which has undergone high-frequency (high-pass) spatial filtering has high-frequency information, such as feature boundaries, edges, and local detail, enhanced. In high-pass filtering, the original DN value of the pixel is subtracted from the low-pass filter or neighborhood average DN value around the pixel. Filtering with 100-percent addback is often referred to as edge enhancement or MTF correction (Chavez, 1974).

Another form of data enhancement used especially in thematic map production is band ratioing. Band ratioing is used to accentuate the gray scale changes in DN values between uniform surface materials and minimize the effects caused by the Earth's topography. This is achieved by dividing the DN value of each pixel in one band or image by the DN value of each corresponding pixel in another band or image. This technique minimizes the effects of sunlight on an inclined land surface, such as the slope of a hill so that pixels with like materials are transformed to similar DN values.

Variations of ratioing can be used to enhance certain features in an image. For instance, "hybrid ratioing" is used in differentiating materials that are not uniform but reflect similar DN values. This is accomplished by combining two ratioed bands with a single band (Chavez, 1975).

Registration

The initial geometric correction of most U.S.-received images is performed at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. Their system corrects errors in the data caused by the sensor (optics, scan mechanism, and detector array geometry), the spacecraft (attitude and altitude variations), and effects due to the Earth's rotation. These corrected digital data, stored on high-density magnetic tapes, are routed to the USGS's EROS Data Center in Sioux Falls, S. Dak., where they are further processed to improve the image's geometry; where image map products are involved, to meet National Map Accuracy Standards (NMAS).

Transforming multispectral scanner image data recorded by a satellite to cartographic format involves the altering of shapes and sizes of the digital input image to conform to the constraints of specific map projections. The image data transmitted usually do not correspond with the geometry of any map. Therefore, it is necessary to transform the digitally recorded image data to fit a particular map projection.

Registration techniques involve the stretching and compressing of the digital image data until they fit the selected map projection. This is usually done by moving pixels from their original positions in a raster array to new positions based on a transform grid derived for the desired map projection. A general geometric transformation program is used to transform the image into one of a number of cartographic projections, such as: Lambert Conformal, Space Oblique Mercator, Universal Transverse Mercator, Albers Conical Equal-Area, Polar Stereographic, Orthographic, and simple Cylindrical. The transformation needed to map the image to the selected projection is established by programs or "projection drivers" which incorporate the appropriate algorithms for the desired projections. The transformation programs currently in use by the U.S. Geological Survey can transform images into either Space Oblique Mercator, Universal Transverse Mercator (UTM) or Polar Stereographic projection (PS). (The UTM projection is normally used when the scene's latitude is 65 degrees or less, and the PS projection when the latitude is greater than 65 degrees.)

The geometric registration of image data collected by a satellite to a map projection requires two stages. First, the spatial locations of pixels on the input image versus their output image pixel locations must be determined. Second, the new DN value for the output pixel must be assigned. The geometric registration parameters are normally determined by locating a series of ground control points for which the true locations are known, and relating their latitude and longitude position to their line and sample (role, column) location on the image. A geodetic-correction processing technique can be used to extract control points by using neighborhoods from previously corrected image data and cross-correlating them with the new image to generate control points. Once the spatial location of the output pixels has been determined, their new DN values can be interpolated from adjacent pixels. This procedure is commonly referred to as resampling, and there are several options that can be used.

The resampling techniques used at the EROS Data Center are either nearest-neighbor or cubic-convolution algorithms. In general, nearest-neighbor resampling is applied by assigning the DN value of the input pixel nearest to the output pixel, while in cubic convolution the weighted DN value of the surrounding sixteen input pixels are used to calculate the output pixel's DN value (see fig. 4). Cubic convolution resampling has been used in USGS-published image maps (e.g., Dyersburg, Las Vegas, Washington, D.C. & Vicinity, and Great Salt Lake & Vicinity).

Recent experimentation with another resampling algorithm, referred to as deconvolution or restoration, has produced visually sharper images than cubic convolution. Restoration is being considered as an alternative to cubic convolution for resampling. For more detail on the comparison of cubic-convolution interpolation and least-squares restoration for resampling Landsat multispectral imagery see Dye, 1975 and 1982, and Kalman, 1985.

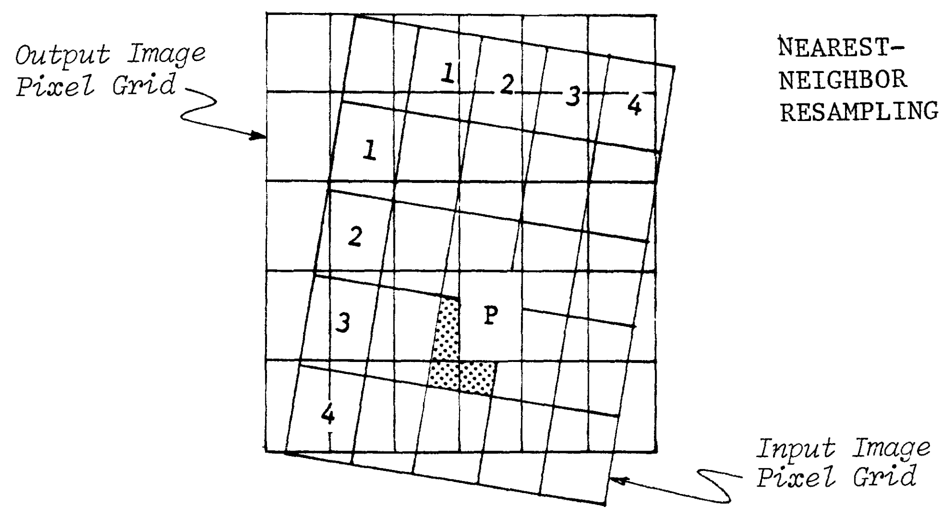
Mosaicking

The digital mosaicking of up to four Landsat scenes is routinely performed using the Image 100 system while large area mosaicking software (LAMS) is use to mosaic any number of scenes (limited only by the amount of disk storage space available). In the general application of either system that portion of each Landsat scene (plus overlap) required to generate the image mosaic is geometrically corrected into the UTM projection. The scene segments so generated each form a control file that contains the output lines and samples. A series of histograms of each segment are run of selected areas in the overlap portions of the segments to determine the contrast stretch required for each segment that will assure that all segments will match when mosaicked. The location of the digitzed mosaic line for each segment is also determined. The desired portion of each segment is then transferred to a file to achieve a mosaicked image, with the desired contrast for each scene segment performed during the transfer.

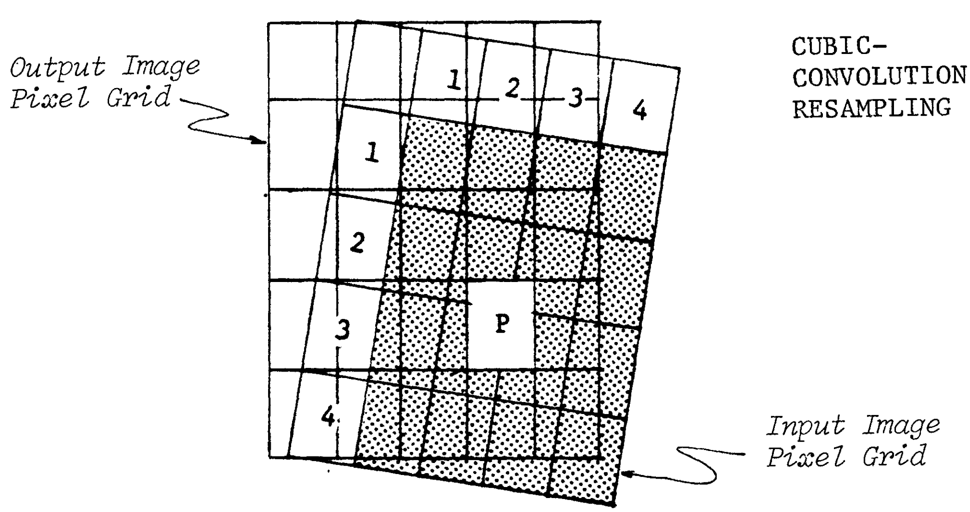
An economical photomechanical technique for mosaicking images on stable-base transparent film also exists and offers an alternative to the more costly digital mosaicking. With this technique, images are scaled to control points and detail is registered to adjacent image scenes. Image densities are matched through photographic processing. Trap windows in peelcoat material are made for each image in the mosaic using scribe scene boundary lines and etched peelcoat of the boundaries. Each image is composited photographically on film through its corresponding trap window. The resulting composite film has the appearance of a single continuous image scene. For more information on the photomechanical mosaicking technique see Warren, 1980.

Tape-to-Film Calibration

The contrast stretch applied to the digital data to convert the DN values to specific gray levels on film greatly influence the appearance of the final



Nearest-neighbor resampling showing the nearest adjacent pixel (stipple pattern) from which the value of the output pixel (P) is derived. The input image pixel grid is skewed with respect to the path of the satellite.



Cubic-convolution resampling showing the 16 adjacent pixels (stipple pattern) from which the value of the output image pixel (P) is derived (weighted value derivation). The input image pixel grid is skewed with respect to the path of the satellite.

Figure 4. Assignment of interpolation values of input image pixel to the output image pixel employing the resampling techniques of nearest neighbor and cubic convolution.

image map product. It is important that the amount of contrast generated on each of the film separates does not exceed the printing density range of the press.

Most of the experimental image maps mentioned in this paper were generated from digital tapes processed at the EROS Data Center (EDC) and converted to film using the Goodyear high resolution (laser beam) film recorder (HRFR). To recreate the image on the film transparencies, a linear density relationship (i.e., the density values on the film negative or positive and pixel DN values have a linear correspondence) is used as the standard black and white film transfer curve in the HRFR. On the HRFR, film is exposed by a sweep beam of light that is digitally controlled on one of 128 (7-bit) discrete gray intensity levels (see section on Image generation and annotation). To duplicate a desired transfer or calibration curve, the HRFR incorporates look-up tables that map input DN values to different gray level intensities (i.e., a mapping function). The look-up table allows the incoming digital numbers to be transformed to desirable film density levels, and in addition can be used to correct for film recorder and film type characteristics. The HRFR look-up table commonly used by EDC to generate film separate is shown in Table 2.

TABLE 2

SAMPLE LOOK-UP TABLE FOR HRFR IMAGING SYSTEM

Pixel Value (7-bit):	0	8	17	25	34	42	51	59	68
Film Neg Density :	.08*	.17	.28	.38	.43	.56	.66	.75	.86
Pixel Value (8-bit):	0	16	34	50	68	84	102	118	136
Gray Scale Step:	16	15	14	13	12	11	10	9	8

76	85	93	102	110	119	127	Pixel Value (7-bit range)
.95	1.05	1.14	1.24	1.34	1.44	1.53	Film Neg Density
152	170	186	204	221	238	255	Pixel Value (8-bit range)
7	6	5	4	3	2	1	Gray Scale Step

* base fog level

Presently, film transparencies for lithographed image maps are generated using a linear transformation that provides a continuous-tone density having a minimum of 0.08 and a maximum of 1.38, for a density range of 1.30. This 1.30 density range is eventually compressed to an optimum 1.00 on a computer scanner/plotter that is used to reproduce the final three screened color separates. The rationale for initially holding to the transmission density range to about 1.30 is based on the maximum density capability of the lithographic press. Consequently, the full dynamic range of the digital data cannot be reproduced. Depending on scene content and the type of contrast stretch used, a few steps at either end of the film annotated gray-scale wedge will appear as a single elongated step. The film transmission density range of 1.00 (plus-or-minus .10) is currently the USGS standard for experimental image maps. More will be discussed on the subject of density range compression under "Tone Reproduction".

Image Generation and Annotation

The EROS Data Center (EDC) currently uses two spot sizes in their laser beam film recorder to define the physical size of a Landsat pixel and, subsequently, the image map scale (Benson, personal comm., November 14, 1985). The spot sizes are 0.057 and 0.038 millimeters or 57 and 38 microns. Landsat MSS images are generated with a 0.057-mm spot size, and TM and Return Beam Vidicon images with a 0.038-mm spot size. TM data that have been resampled to a 20-meter pixel resolution--TM data as it comes from Goddard is resampled to 28.5-meter pixel--would result in a 1:526,316 map scale (i.e., a ratio of 20 meters over 0.038 mm = 1:526,316). The final scale of the image map is determined by the photographic enlargement factor. For example, the USGS Dyersburg TM experimental image map was enlarged by a factor of 5.263 to generate a product at a 1:100,000-scale (526,316 over 5.263 = 100,000). The size of pixels per millimeter on the final Dyersburg Image Map can be derived by multiplying the enlargement factor by the spot size (5.263 x 0.038mm = 0.200mm) and used to compute the map ratio of 1/.200mm, or 5.0 pixels per millimeter. However, in the computer scanning of the separates, additional resampling may change the final pixel size, since the graphic arts scanner performs a 1,000 line per inch resampling in converting continuous-tone film imagery back into digital data for photographic processing. The printing standards for optimum pixel-to-scale of an image map have not been firmly established at this writing; however, about 3.3 pixels per mm has been used by the USGS at map scale with acceptable results (see Colvocoresses, 1984).

The black and white film transparencies generated for use in lithographic printing of an image map requires special annotations. These annotations consist primarily of registration tick-marks, gray scales, and alphanumeric data that provide important lithographic control information. The annotations are generated by translating alphanumeric characters into blocks of pixels. For example, on a film generated scene by EDC, one band of MSS data has 3,385 scan lines each consisting of 3,620 samples per line. Of the 3,385 scan lines in a frame, 2,983 lines are image lines, 200 lines are used for the frame numbers and registration tick-marks above the image, and 202 lines are used for the registration tick-marks, path and row number, gray scale, and other annotation information below the image. Of the 3,620 samples, approximately 3,240 are image samples, approximately 308 are for left and right zero fill, and 36 samples on each side for the left and right side coordinate tick-marks.

Primary gray-scale control is added on the film separates to guide the printing of the image maps. These gray scales are constructed from blocks of pixels containing uniform digital values or densities. On EDC laser-beam HRFR products, the digital format is 7 bits (0-128) with 0 representing black and 127 white, with blocks of pixels separated into 16 gray scale steps. On other imaging devices the digital range is represented by using 8 bits (0-255) with blocks of pixels separated by 16 to 40 gray-scale steps. Until recently, three distinct EDC gray scales had been used for controlling exposure in the pre-press processing for image maps (see fig. 5). The 16-step gray scale located directly below the image represents a linear density gradation of the look-up table that is used to record or map the digital values on to film. This particular output linear scale has been relocated to the top of the image and will be the only scale retained on future film

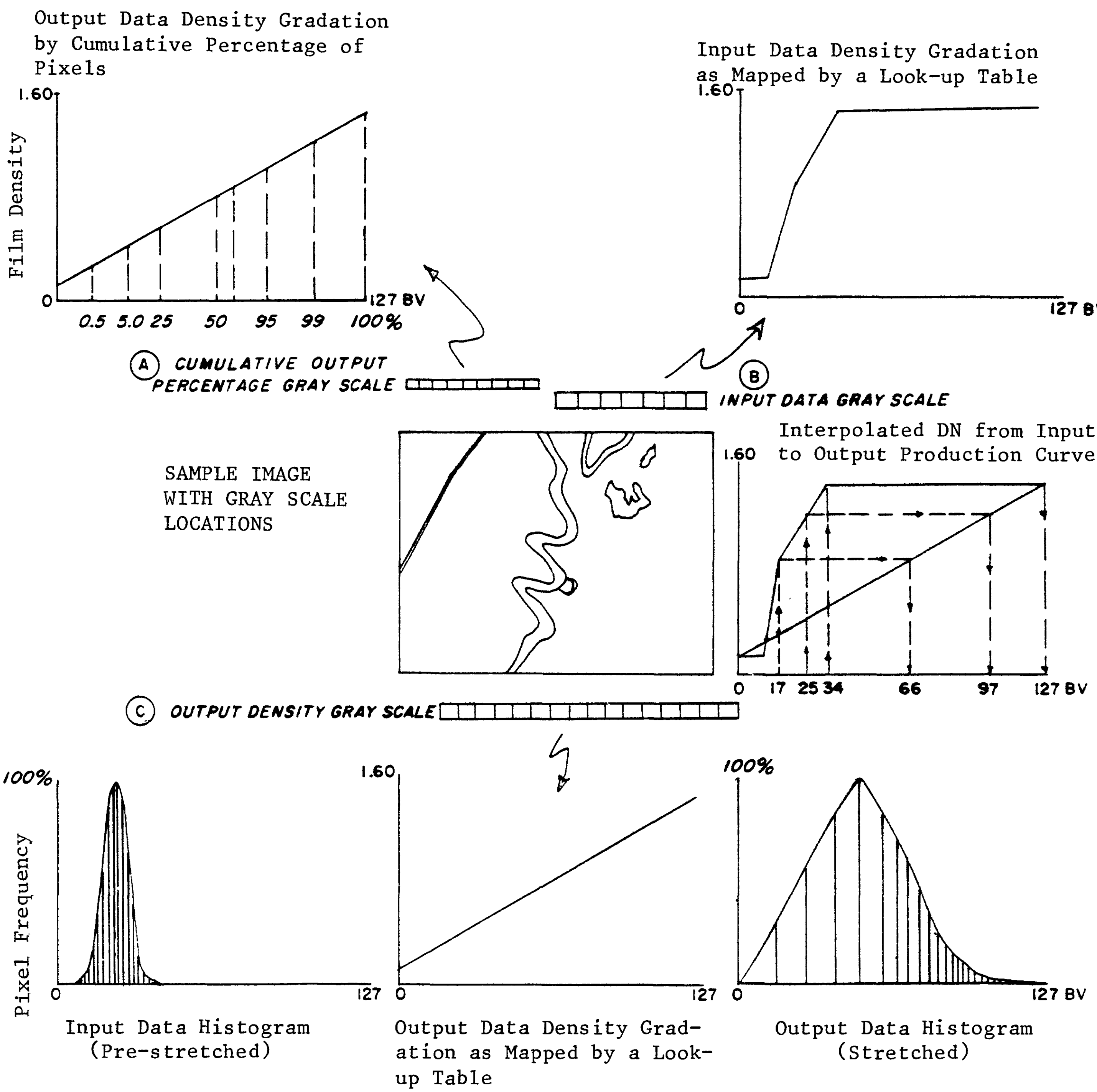


Figure 5. The relationship of the three EDC density gray scales with the digital input and output image data.

separates or color transparency for image map products. The second gray scale, located above the right half of the image, represents the density gradation of the input image before stretching as plotted against the output film density values that are generated by the look-up table. From this particular gray scale, the selected output DN values can be determined by comparing the input data production curve with that of the output linear curve (see right center illustration, fig. 5). The third gray scale, located above and on the left of the image, represents the cumulative percentage levels of the output density. Each block along this gray scale defines the cumulative percentage of pixels as they relate to the output film density. The DN value figures shown in figure 5 represent the cumulative percentage after contrast stretching as plotted against the output density values. The cumulative percentages as illustrated in figure 5 (A) are taken from the output histogram and the density values calculated using the equation of the LBR look-up table (R.J. Thompson, written commun., July 18, 1983).

Band and Color Options

The band combinations and color options available for portraying a Landsat scene are numerous, especially when using the six multispectral bands of the Thematic Mapper. To evaluate optimal combinations of bands and colors, the planned use of the image map and information of primary interest to the prospective users must be known. An analysis of the relative spectral properties of features that are of primary interest in the image will assist in choosing the appropriate bands. After the bands are chosen, the color to be used for each band is selected to enhance the features of primary interest and the overall image. This section will discuss spectral reflectance characteristics and provide a brief overview of techniques used for determining the optimum band and color combination for portraying a Landsat scene.

The wavelengths available for image mapping from Landsat extend from the visible, at about 0.45 micrometers (um) to the mid-infrared at 2.35 um (see fig. 6). The far-infrared band (TM band 6 at 10.4 to 12.5 um) is reserved primarily for thermal image analysis and not used in general image mapping.

The reflectance properties of surficial materials are often presented as spectral reflectance curves relating the percentage of incident energy that is reflected as a function of wavelength (fig. 6). The general spectral reflectance curves for vegetation, soil, and water, show that these natural surface materials normally reflect different amounts of electromagnetic radiation at different wavelengths. Vegetation and soil reflect greater percentage of energy in the near-infrared band than does water, which reflects the highest percentage of incident energy in the visible band. The high spectral reflectance of vegetation beyond 0.7 um is influenced strongly by the intense absorption of near-infrared wavelengths by chlorophyll. The reflectance properties of soils are strongly influenced by their mineral composition and moisture content. Commonly, drier soils reflect more energy than moist soils at any given wavelength. Unlike vegetation and soils, clear water is a very poor reflector of the near-IR wavelengths. It should be noted that the process of reflection takes place within one-half wavelength of a material's surface (in the molecular structure of the material) and results in the instantaneous re-radiation of the incident energy. The reflectance properties of surface material can vary due to changes in illumination, season, environment, physiological conditions of plants, topography, and moisture levels.

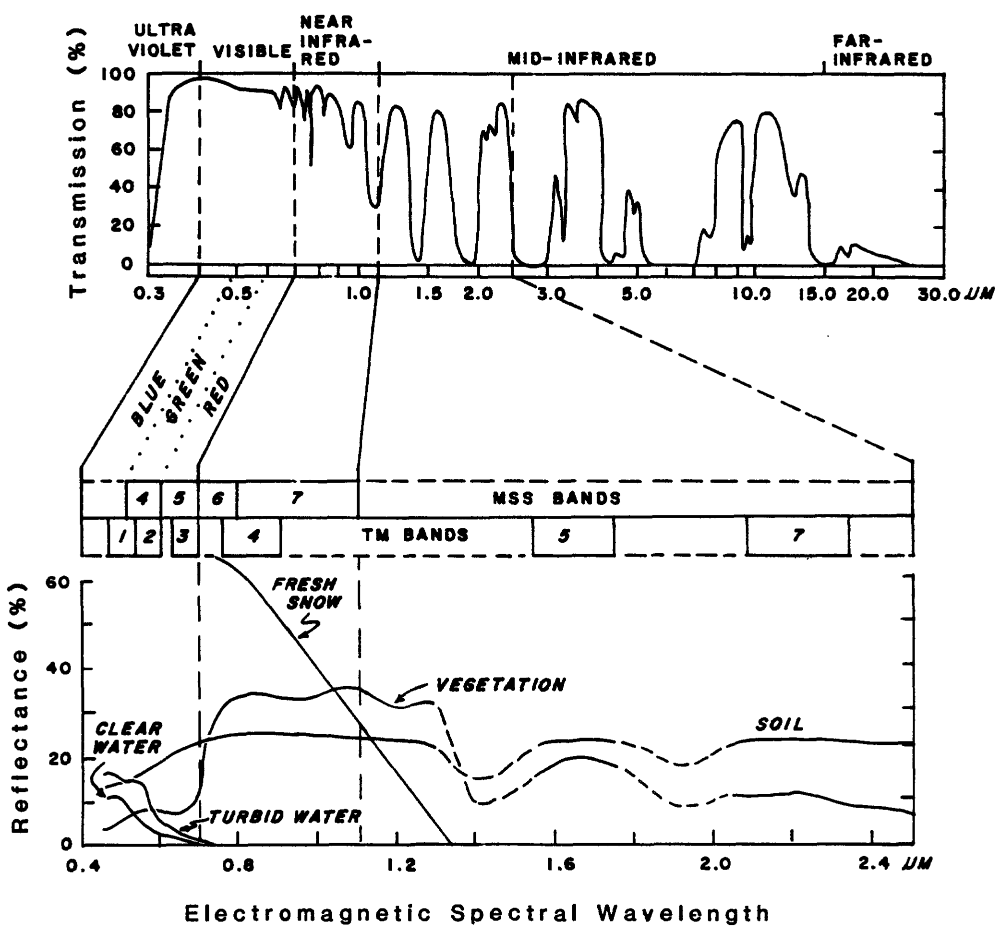


Figure 6. General absorption spectrum of the atmosphere and spectral characteristics of primary cover types in relation to multispectral scanner (MSS) and Thematic Mapper (TM) Landsat bands.

Different Landsat MSS and TM bands combinations may vary in suitability for image feature interpretation. The high number of combinations that are possible with TM data, for example, presents a selection problem. To reduce the number of possible combinations, several ways of approaching this problem have been introduced. One quantitative approach for determining the optimum TM band combination, called the "Optimum Index Factor" (OIF) allows the user to statistically rank band combinations taken three at a time (Chavez, Berlin, and Sowers, 1982). The combination rankings are based on the amount of correlation and total variance among the three TM bands being used in each of the particular three-band combinations. They are quantitatively ranked in the order of the least duplication with the most information as measured by variance. This systematic approach results in the automatic selection of bands for use in the production of a color composite, for further processing, or to generate an image map on the basis of statistical information content alone.

Tables 3 and 4 show the correlation matrix and OIF ranking for two TM images (Washington, D.C. and Dyersburg).

TABLE 3

BAND CORRELATION MATRIX, WASHINGTON, D.C.

1	1.00	--	--	--	--	--	--
2	.91	1.00	--	--	--	--	--
3	.83	.89	1.00	--	--	--	--
4	.27	.42	.34	1.00	--	--	--
5	.45	.56	.62	.67	1.00	--	--
6*	.24	.26	.32	.44	.55	1.00	--
7	.65	.72	.78	.46	.90	.49	1.00
	1	2	3	4	5	6	7
AVE	60.90	24.80	26.10	40.90	52.10	116.50	20.20
SD	5.68	3.78	5.32	10.93	15.77	2.48	7.69

OIF FOR WASHINGTON, D.C.
(TM 6 = THERMAL BAND NOT USED)

RANK	COMBINATION **	OIF
1	(1,4,5)	23.46
2	(3,4,5)	19.64
3	(2,4,5)	18.61
4	(1,4,7)	17.70
5	(4,5,7)	17.00
6	(1,3,4)	15.24
7	(3,4,7)	15.12
8	(1,5,7)	14.61
9	(1,3,5)	14.08
10	(2,4,7)	14.04
11	(1,2,5)	13.18

12	(1,2,4)	12.82
13	(2,5,7)	12.5
14	(3,5,7)	12.51
15 (MSS)	(2,3,4)	12.20
16	(2,3,5)	12.06
17	(1,3,7)	8.26
18	(1,2,7)	7.52
19	(2,3,7)	7.03
20 (NC)	(1,2,3)	5.63

** SIX BANDS COMBINED THREE AT A TIME GIVES 20 COMBINATIONS

TABLE 4

BAND CORRELATION MATRIX, DYERSBURG, TN

	1	2	3	4	5	6	7
1	1.00	--	--	--	--	--	--
2	.93	1.00	--	--	--	--	--
3	.94	.94	1.00	--	--	--	--
4	-.36	-.33	-.47	1.00	--	--	--
5	.42	.48	.43	.29	1.00	--	--
6	.40	.42	.42	-.16	.50	1.00	--
7	.69	.72	.73	-.10	.89	.57	1.00

	1	2	3	4	5	6	7
AVE	36.9	15.4	13.8	51.4	39.1	69.9	14.2
SD	3.9	2.8	4.8	13.7	11.2	3.0	6.9

OIF FOR DYERSBURG
(TM 6 = THERMAL BAND NOT USED)

RANK	COMBINATION **	OIF
1	(1,4,5)	26.82
2	(2,4,5)	25.07
3	(4,5,7)	24.92
4	(3,4,5)	24.90
5	(1,4,7)	21.40
6	(2,4,7)	20.29
7	(3,4,7)	19.58
8	(2,5,7)	16.09
9	(1,3,4)	12.71
10	(1,3,4)	12.55
11 (MSS)	(2,3,4)	12.26
12	(3,5,7)	11.17
13	(1,5,7)	11.03
14	(2,3,5)	10.17
15	(1,2,5)	9.78
16	(1,3,5)	8.96

17	(1,3,7)	6.61
18	(2,3,7)	6.05
19	(1,2,7)	5.79
20 (NC)	(1,2,3)	4.10

In comparison with the statistical approach above, a subjective approach has been the most used technique for determining the spectral band combination and color selection. This trial and error process of subjectively deciding what image iteration contains the desirable perceptual appearance results in a band and color combination that does not usually correspond to the OIF ranking. For example, TM band combinations 1, 3, and 5 and 2, 3, and 5 were chosen for the final combinations for the Washington, D.C. and Dyersburg image maps, respectively. Based on the OIF, these combinations were ranked 9th and 14th (see OIF tables 3 and 4 above). This difference in spite of their ranking may be attributed to the importance given to personal preference in the perceptual or aesthetic appearance of an image over the maximization of statistical informational content. For instance, in the Washington, D.C. image map the cultural features, such as roads and runways were subdued by the highly reflective vegetation in the TM band 1, 4, and 5 combination (OIF #1), thus, band 4 was replaced by 3, even though this reduced the overall informational content of the final product (Colvocoresses, 1984).

The search for a systematic approach for optimum band and color selection is ongoing within the USGS and may eventually reduce the number of iterations that are needed to produced an acceptable image product. Until such time, however, the choice of spectral bands and color combination in some cases may continue to be the result of subjectively selected products of processed before-and-after iterations of image scenes. One must keep in mind that the role of choice of color alone for each spectral band is largely determined by the blue, green, and red light of the visible spectrum. For example, the combination of TM bands 1 (blue), 2 (green), and 3 (red) is representative of a natural-color image. For lithographically produced image maps, the so-called "process colors" yellow, magenta and cyan are used to reproduce the various colors of the visible spectrum. By overprinting various tonal ranges of these colors, a wide range of color may be produced. This sequence of colors (i.e., yellow, magenta, and cyan) is normally applied to whichever band combination is selected. All but band combinations 1, 2, and 3 of TM, and all MSS band combinations can produce a false-color composite. Vegetation is often portrayed in red (MSS bands 6 and 7, and TM bands 4, 5, and 7) rather than green (MSS band 4, and TM band 2) because of its high reflective response in the infrared region. The false color composite image of the published Washington, D.C. image map was formed by printing TM bands 1 (blue), 3 (red) and 5 (near infrared) in yellow, magenta and cyan, respectively.

Each Landsat film separate is converted into halftone dots ranging from about 3-percent dot area (highlight) to 96-percent dot area (shadow) to be reproducible lithographically. By varying the percentage of dot area the intensity of the hue and contrast of the color can be adjusted. As shown in figure 7, the process-color dot combination for reproducing blue is achieved by printing magenta and cyan dots (M+C=B) to absorb green and red, respectively, from white light, reflecting only blue. Similarly, overprinting yellow and cyan dots result in absorbing [illegible] blue and red and reflecting green (Y+C=G); and red is reflected by printing magenta and yellow dots (absorbing green and blue) or Y+M=R.

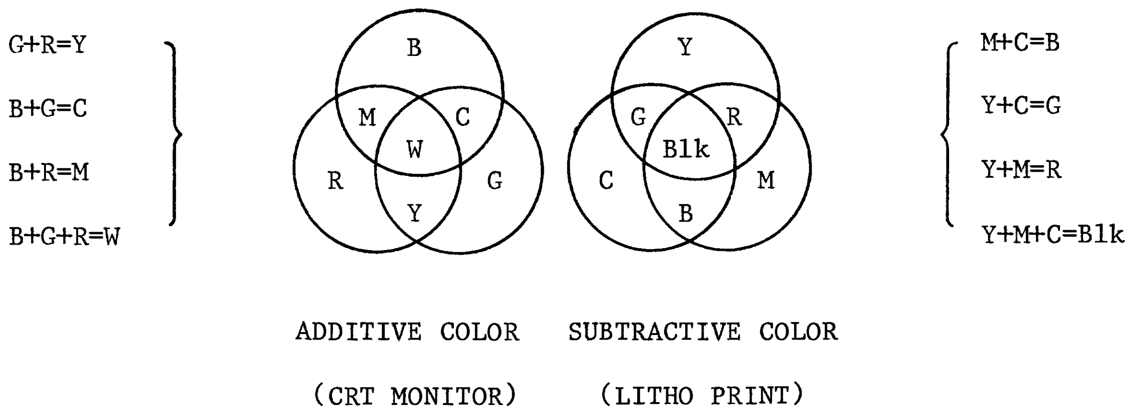


Figure 7. Color combinations of additive primary colors as displayed on a CRT monitor and subtractive primary colors as displayed on a lithographic print. B = Blue, G = Green, R = Red, Y = Yellow, M = Magenta, C = Cyan, W = White, and Blk = Black.

Color Image Reproduction

According to the basic principles of color, white light, which is composed of all colors, can be created by adding blue, green and red light together. The printing inks (also referred to as process colors by lithographers) designed to reproduce these additive primary colors on white paper are yellow, magenta and cyan. These colors subtract, or absorb, a portion of the white light (or visible wavelengths), therefore, are called "subtractive primary colors."

When three different black-and-white Landsat bands are displayed simultaneously on a color video monitor, color combinations are made by addition, i.e., displaying each band in either blue, green, or red. When a Landsat scene is printed as a image map, subtractive combinations are used. Figure 7 assists in illustrating these different color combinations.

To summarize, in recreating the Landsat digital data in analog form, the DN values of each band are recorded to give a film record of the sensor output. The spectral colors of the visible spectrum (blue, green, and red) are created on paper through the applications of subtractive primary color (yellow, magenta, and cyan, respectively). As shown in table 5, by overprinting various tonal ranges of yellow, magenta, and cyan, any color such as green, brown, violet, purple and orange may be produced. To vary the tonal ranges, screen tints of 3% to 96% are used in image mapping. The infrared wavelength bands are generally treated as red in color reproduction, thus are printed as cyan (i.e., Y+M=R).

Table 5. - Overprinting Three Color Process Inks

Ink Color	Overprint	Absorbed Colors	Reflected Colors	Color Sensation
none	none	none	white light	white
yellow	none	blue	mixture of green & red	yellow
magenta	none	green	mixture of blue & red	bluish red
magenta	magenta on yellow	blue & green	red	red
cyan	none	red	mixture of green & blue	greenish blue
cyan	cyan over yellow	blue & red	green	green
cyan	cyan over magenta	green & red	blue	blue
cyan	cyan over magenta over yellow	blue, green & red	none	black

Source: V. Strauss, 1967.

Prepress Film Preparation

Once the Landsat bands for the image map have been selected, a digital Landsat image may generate hundreds of distinctly different colors. Most of those colors can be reproduced by a mixture of the subtractive primary colors. In the printing phase, each of the three process ink colors will be transferred to paper stock by a separate press plate. To make these press plates, three separate final-size black-and-white screened film positives or negatives are required to provide the tonal gradations that each of the plates will render. Figure 8 illustrates the entire color separation and reproduction steps taken in the production of the image map.

The image map separation method currently used by the U.S. Geological Survey for the reproduction of Landsat images made from HRFR continuous-tone film negatives or positives involves the use of a computer-controlled scanning device. This particular separation method for prepress film preparation is treated under the following headings: (1) Computer-controlled scanning, (2) Preliminary examination of tone density, (3) Halftone screening, (4) Neutral balancing, (5) Tone reproduction, (6) Scaling and control, and (7) Color proofing.

Computer-Controlled Scanning. The CP340 Hell Scanner is currently the principal electronic computer-controlled scanning device used for preparing the final-size film separations of USGS satellite image maps. Scanner devices like the Hell CP340 are capable of making the necessary Landsat black-and-white film separations directly from either a color transparency or black-and-white film transparencies. In a typical exercise, Landsat HRFR continuous tone film separates and two gray scales (at 0.10 and 0.15 step increments) are mounted on a transparent rotating drum (analysis and exposure drum, see figure 9). A small spot of light is projected from the inside of the drum through the transparency into an optical system which divides it into gray tones. The divided lights are then individually projected onto photomultipliers cells for conversion from an optical analog signal to a electrical digital signal. The scanner's computer, with the operator's assistance, then carries out such functions as neutral balancing, screening and enlargement. NOTE: The Hell Scanner reproduces more consistently when scanning continuous-tone positives, however, until recently most image-map projects were reproduced in negative form.

The scanner's analyzing and exposing drums are usually coupled together and rotate as one. Each time the drum rotates, one scanned line of the image is sent to the exposing head either immediately or during the following revolution. For generating halftoned separations, the "screen's rulings" are actually produced by an electronic dot generator, which can reproduce most conventional screen angles.

Hell scanner enlargements of up to 44-by 50-inch are possible from the regular Landsat 9- by 9-inch HRFR separates. Since scanning and enlarging are carried out in a single step, density prediction is made fairly accurate. The scanner's densitometer can read either continuous-tone density or, for screened separations, the percentage dot size. Two gray scales, however, are mounted with the HRFR separate to establish a correlation between the dye density scales, the silver density scale on the separate, and the scanner's densitometer.

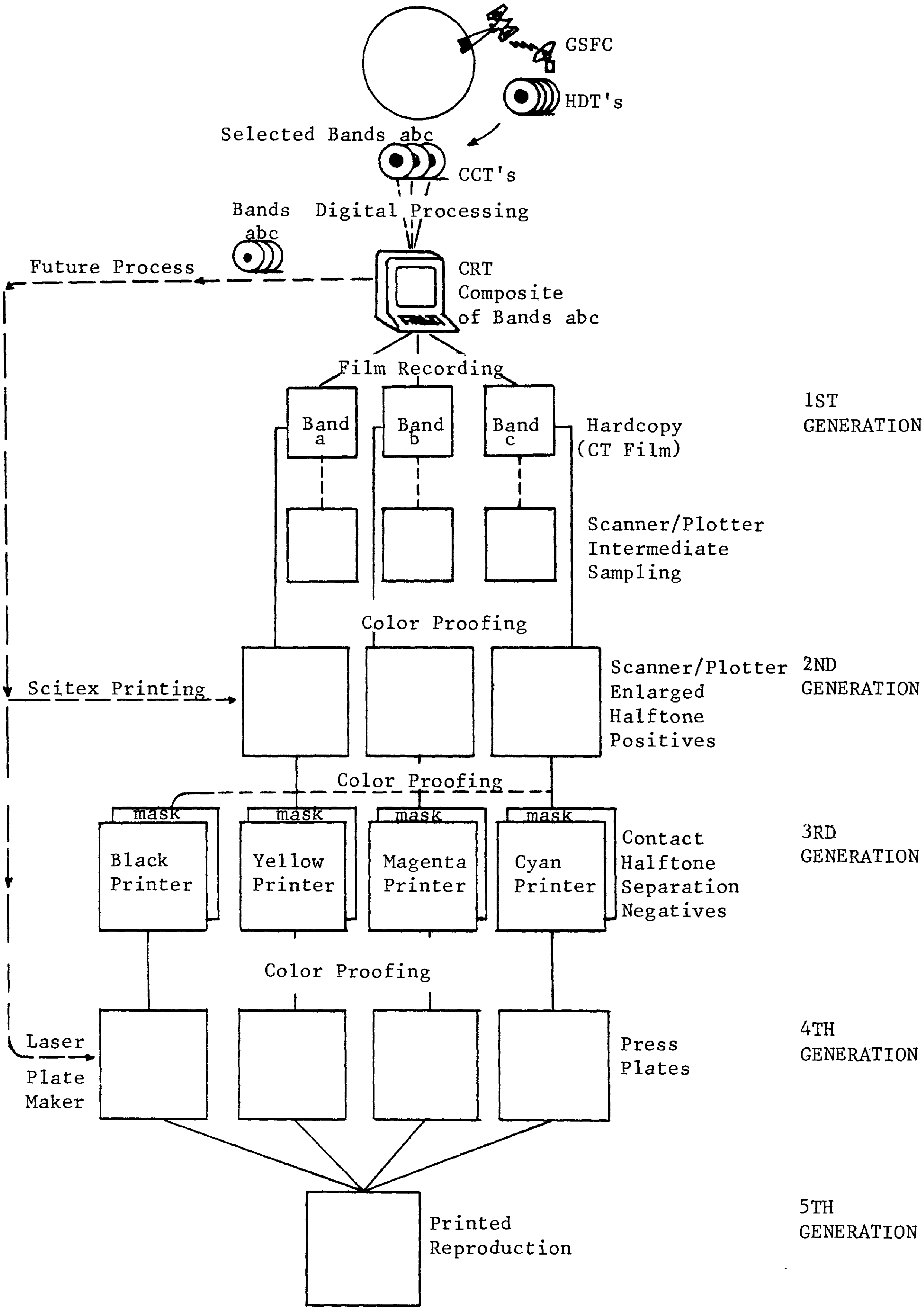


Figure 8. The color separation and reproduction steps of satellite multispectral image map development.

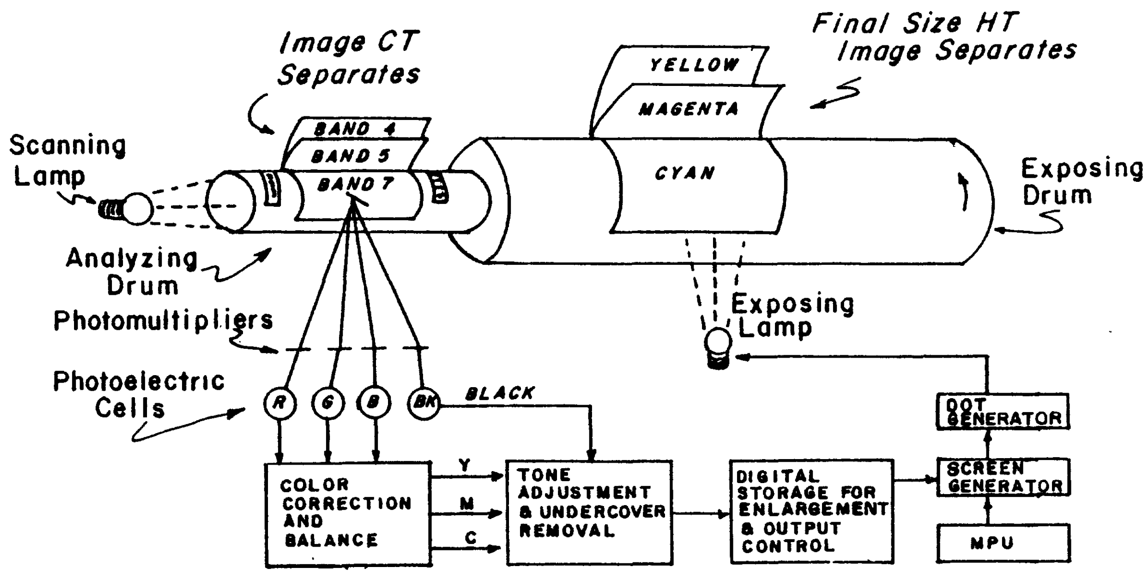


Figure 9. Simplified schematic of an electronic computer-controlled scanning device.

Ongoing experimentation by the USGS on an up-graded Scitex Model 280 Electronic Laser Plotter has introduced new possibilities for the quality reproduction and separation of Landsat digital image data directly from the computer-compatible tape (CCT), as opposed to the intermediate film separates of the HRFR, or the color transparency of the McDonald Dettwiler Color 240 Recorder.

Preliminary Examination of Tone Density. Comparing gray-tone densities is the first of two techniques used for preliminary examination of the Landsat HRFR continuous-tone film transparencies. The densitometric analysis of the gray scale wedges of each reproduced separate provides a visual indication of the tone separation in the highlight, middletone, and shadow areas.

In the first technique, a scanner-produced screened positive print of each HRFR separate is generated and reviewed to determine whether tone curve adjustments are necessary. In general, the HRFR separate representing cyan should be higher in contrast, or richer in detail, than the yellow and magenta separates in order to produce a neutral gray on the linear grayscale. If the cyan separate produces a pleasing black-and-white print, there is a high probability that the tone contrast of the cyan printing separate (i.e., the final-size halftone positive), will also furnish a pleasing reproduction.

The second technique of examining tone density ranges utilizes a photographic-paper color composite print of the HRFR separates. Although, the color paper print is not absolutely identical to the color or contrast of the final lithographed product, it provides a good guide for determining overall density shifts and screen dot-area aimpoints, especially for the cyan separation. By matching principal areas of the color print with a color chart printed to lithographic standards, halftone integrated dot density or percent dot-area aimpoints for the cyan separate can be deduced. Aimpoints for the yellow and magenta separates are usually not necessary because neutral balance adjustments adequately shift their dot size.

Halftone Screening. In the reproduction of the continuous-tone Landsat image film by lithography, it is necessary to transform the HRFR separates into a gradation of dots or "discontinuous tone." The standard USGS screen "ruling" most often employed is 175 lines per inch (Lpi). The selection of the ruling is accompanied by conventional screen angles of 15, 45, 75, 90, and 105 degrees.

Customarily, a 75 degree screen angle is chosen for the magenta film separate, 90 degrees for yellow; and 105 degrees for cyan (45 degrees for black in preparation of press plates) which reduces Moire interference.

The percent of dot area generated by a 175-line separation screen positive generally ranges from a 3 percent value (0.013 integrated halftone density) at the highlight of the tone curve and 96 percent value at the shadow end (1.398 integrated halftone density). Beyond 96 percent, the dots merge to produce a solid image; conversely, less than 3 percent dot in the highlights the dots fade to produce a paper white image. The effect of tonal differences of the finished halftone print is produced by the amount of ink which is observed by the eye in proportion to the amount of white paper that surrounds it. In other words, the ratio of printed to unprinted area determines the depth of tone density (e.g., 75 percent dot area is equivalent to 25 percent unprinted paper).

Neutral Balancing. In the scanner separation and reproduction of color image maps, one of the fundamental requirements is the overprinting of a gray scale with three-color process inks. An attempt to overprint yellow, magenta, and cyan separates with matching gray scales (equal dot sizes) would result in the reproduction of a brown tint rather than gray. The brownish tint is caused by the unavailability, commercially, of a perfect set of process inks. Therefore, it is necessary to neutralize the effects of the ink pigment deficiency by balancing the 3-color scanner separates so that they will print a neutral scale of gray. This is accomplished by varying the dot size of the cyan printing film (halftone-positive) relative to those of the yellow and magenta printing films. This is because yellow and magenta are more dominant than cyan, therefore, more cyan is needed to acquire a neutral hue or balance when overprinting. Neutral balancing by the scanner during 3-color separation of USGS experimental Landsat image maps is achieved by increasing the dot size of the cyan separate by approximately 10 percent at the midtone over the yellow and magenta separations (as adjusted for ink, paper, and press variables).

Tone Reproduction. Quality reproduction of the Landsat digital image is largely contingent upon the limitations of the reproduction system used during the prepress film preparation and printing process. The relationships among the variables of screening, neutral balance, and scanner operation, plus press plates, ink, paper stock and printing condition in the printing process, must be controlled to raise the probability of a good color image map print. The procedures employed for controlling these variables involve a densitometric evaluation and graphical analysis of the tone reproduction of the HRFR film separates or Color 240 Recorder transparency of the Landsat digital image. To facilitate this procedure, gray scales are added before separations are produced.

In the offset printing of image maps the total density range of the HRFR film negatives or Color 240 Recorder transparency usually cannot be reproduced and, therefore, should be compressed. In using the electronic computer-controlled scanner a lesser amount of density range reduction is required, as compared to the purely photographic process.

To establish the desired tone reproduction of the film separates or color transparency, aimpoint controls are determined. These aimpoints, which consist of the highlight one-quarter tone, midtone, three-quarter tone, and shadow of the tone curve, are normally developed as a result of either the densitometric evaluation of the gray scales of photographically produced halftone black and white prints of each original separate, or the color matching of a photographic color print with a color chart printed to lithographic standards, as discussed earlier. The desired aimpoints are plotted as tone reproduction curves in percent of dot area, on graph paper (Tint-Density to Dot-Area Conversion Chart) for the cyan separate and the yellow + magenta separates. The two plotted tone curves incorporate the necessary relationships for the correct tone reproduction on a given system.

Predictions about the printed image map and what changes would make better tone reproductions are assessed from the model tone curves. The halftone reproduction midtone aimpoints for most USGS experimental multispectral color image maps that were generated from HRFR separates were set at gray scale step 8 at a range of approximately 45 percent to 65 percent dot area. Gray scale step 8 corresponds to the digital number (DN) value of 68 (midpoint) on the EDC's 7-bit format (see bottom graph of figure 10). The tone curve endpoints are generally assigned a minimum of 3 percent dot size in the highlight area and a maximum 97 percent dot size in the shadow area, which often correspond with gray scale steps of 14 and 2 or DN values of 17 and 119, respectively. The one-quarter and three-quarter aimpoints vary the most in the percentage of dot size and corresponding gray scale step. Their adjusted values are based on some scene-dependent factor, i.e., primary features really important in the scene. For example, if roads and runways are important, their definition will increase or decrease by bringing the quarter-tone closer or further, respectively, from the midtone. Likewise the midtone can be adjusted toward the highlight aimpoint to increase similar detail.

To illustrate, figure 10 shows the interrelationship between the prepress variables discussed above and the range of a DN frequency histogram of a computer-[illegible] tape. The histogram at the top of figure 10 contains the normalized pixel count of the output digital data of the Landsat image scene. In the original output data, a given DN corresponds to a pixel percentage value (normalized to 100 percent) drawn from the corresponding point at the intersection of the appropriate output data curve. This percentage value is related to the maximum count of picture elements of one

DIGITAL TO DENSITY
SCALE LOOK-UP TABLE

Step	Digital No.	Density
16	0	.06
15	8	.15
14	17	.25
13	25	.33
12	34	.42
11	42	.52
10	51	.60
9	59	.70
8	68	.80
7	76	.88
6	85	.98
5	93	1.07
4	102	1.17
3	110	1.25
2	119	1.36
1	127	1.46

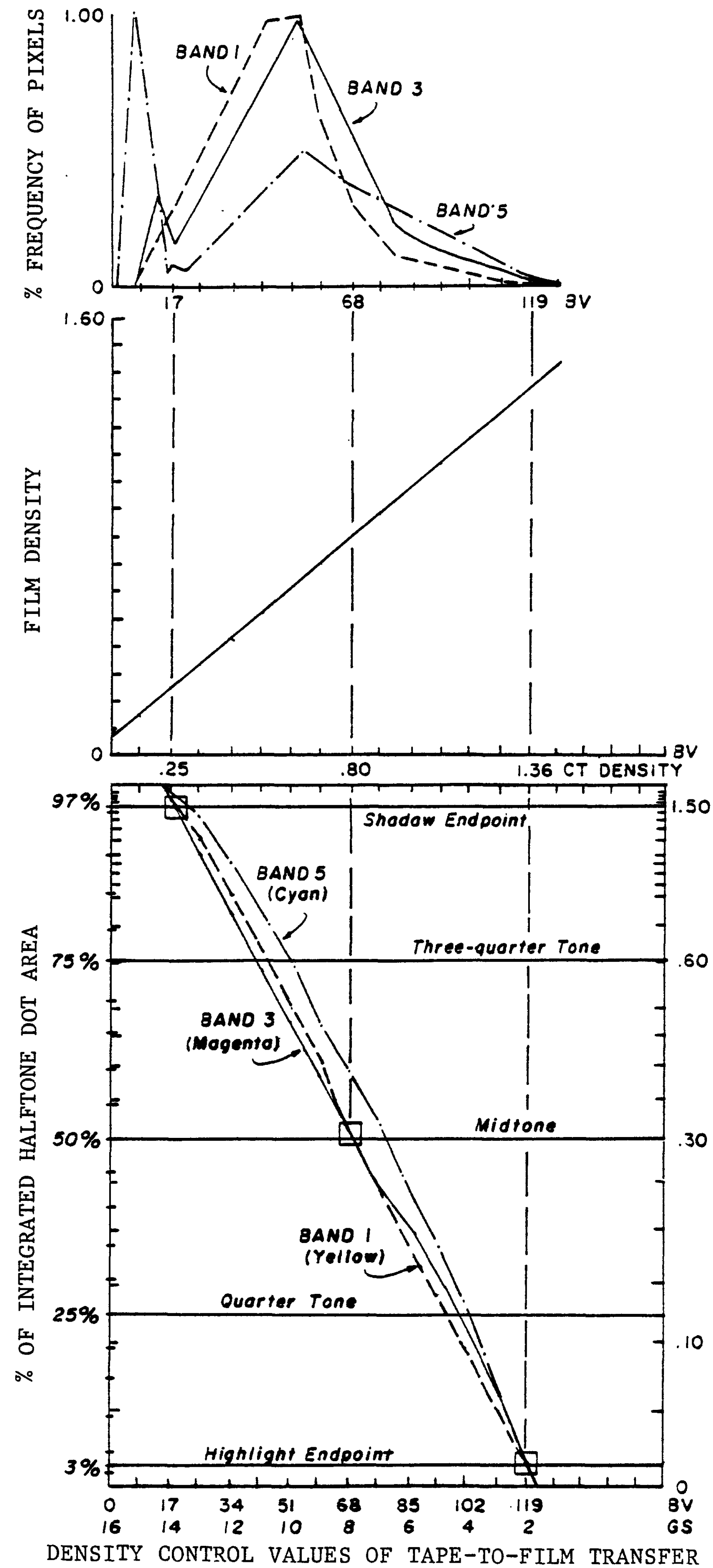


Figure 10. The output stretched data histograms of bands 1, 3, and 5 with the digital-to-density transformation and halftone reproduction curves of the Washington, D.C., and vicinity TM Landsat image map (USGS, 1984).

digital value displayed as 100 percent on the ordinate axis. In the middle graph (digital to film transfer distribution) the points of intersection of the vertical broken lines and the tone curve show the aimpoint densities of the HRFR separation negatives. When following the broken lines into the bottom graph (halftone transformation curve) the required aimpoints and dot sizes are found for the halftone film which produce the neutral balanced tone values in the press plates. The amount of tone compression of the original output film density range can be noted by comparing the DN values of the original endpoints of the stretched output data of the histograms of bands 1, 3, and 5 (top graph) with the shadow and highlight aimpoints of the halftone transformation curves (botton graph).

Scaling and Control. Upon the completion of the tone reproduction of the original film negatives, predetermined enlargement factors for x and y dimensions are set for the preparation of the final-size film separates. These x and y enlargement factors may differ due to scale adjustment for the laser-beam HRFR error. To determine the final x and y predicted enlargement factor the following scale factor is used:

$$\frac{\text{Pixel Size x 1000/}}{\text{HRFR Spot Size}} - \frac{\text{Final Image}}{\text{Map Scale}} = \frac{\text{Predicted}}{\text{Enlargement Factor}}$$

Whereas, by taking TM pixel data resampled from 28.5 to 20 meters and a spot size of .038mm (EDC's laser beam HRFR operates on two modes to define physical pixel size, .038mm and .057mm), to get a final scale of 1:100,000 a 5.263x enlargement is predicted.

To determine the actual enlargement factor for each film negative's x and y dimensions (to include the diagonal measurements), scale adjustments for error in the HRFR system are incorporated. Tolerances of 0.10 - 0.12 percent are provided for aim targets (0.10% x, x', y, y' and 0.12% for diagonals). Final factors for x enlargement and y enlargement are then transformed into a check grid on a stable-base film for overlay. The final-size separation positives must fit the x and y corner marks of the check grid within 0.002 inch (USGS standard). The yellow and magenta separates must also register precisely to the cyan separate to assure overprinting color problems do not occur.

In the reproduction of each final-size separation, exposure control step wedges are placed beside the continuous-tone positive on the scanner's analyzing drum and printed on the exposing drum adjacent to the body of the image map. These wedges are then read with a graphic-arts densitometer to determine if density aimpoints are met. These particular transmission density control tolerances are as follows:

Halftone Integrated Density Tolerance	Tone Curve Aimpoints
0.01	Highlight
0.02	1/4 tone
0.02	Midtone
0.07	3/4 tone
0.15	Shadow

Note: The aforementioned exposure control step wedges consist of two Kodak dye density gray scales at 0.10 and 0.15 increments. These two scales, in addition to the silver density scale of the original film negative, are also utilized in the prepress film preparation for calibrating the scanner densitometer with the master graphic-arts densitometer.

Color Proofing. The last phase of prepress film preparation is proofing the color composite of the three final-size separations halftone positives. These positives will be transformed into the halftone negatives used for making the press plates, so a color composite will give a preview of the printed image map.

The preparation of the often used Cromalin color proof involves a photomechanical series of sensitizing, exposure, and development steps. In a typical exercise, a light-sensitive polymer film is laminated to a white plastic sheet. The polymer-covered sheet is then superimposed in register by the yellow halftone separate (emulsion-to-emulsion) in a vacuum frame and exposed to light. The polymer film is peeled off and the exposure is chemically developed with a pigmented toner. A new polymer film is laid over the original white plastic sheet and the series is repeated until the remaining two process colors have been produced (i.e., magenta and cyan). Once the process is completed the color proof is ready for evaluation and approval. A Duraflex color proof production process has been recently adopted by the USGS which is much faster and less costly than Cromalin.

Color Separation Assembly

In assembling the scanner halftone positives for platemaking certain steps must be taken to assure consistency in color separation and reproduction (see fig. 11). These steps commonly referred to by lithographers as "stripping" consist of three operations: (1) image map layout, (2) registration and assembly, and (3) contact negative preparation and proofing. The exact procedure varies with the available equipment. The following description is based on conventional methods and equipment utilized on most of the latest USGS multispectral image map products.

Image Map Layout. A "mock-up" or "dummy layout" of the image map is designed early in each image map project. The size of the finished map is controlled by dimensional limitations, such as press size, paper stock size, map finishing requirements, and normal printing allowances (e.g., gripper edge, trim lines, etc.). Design of the image map must also be guided by the accuracy required in the placement and registration of the film positives and overlays.

To assure accurate positioning, a border neatline is plotted on a register-punched white plastic layout sheet directly from the scanner halftone positives. This neatline, in addition to any others on side panels, serves as reference in the registration and assembling operation. Additional reference marks that are plotted on the master layout include the location of the credit legend, agency name, foreign language consideration, scale data, and other collar type information. Also considered are the location of density scales, Graphic Arts Technical Foundation (GATF) color test strip, and other control guides that are printed on the map, but that are removed in map finishing.

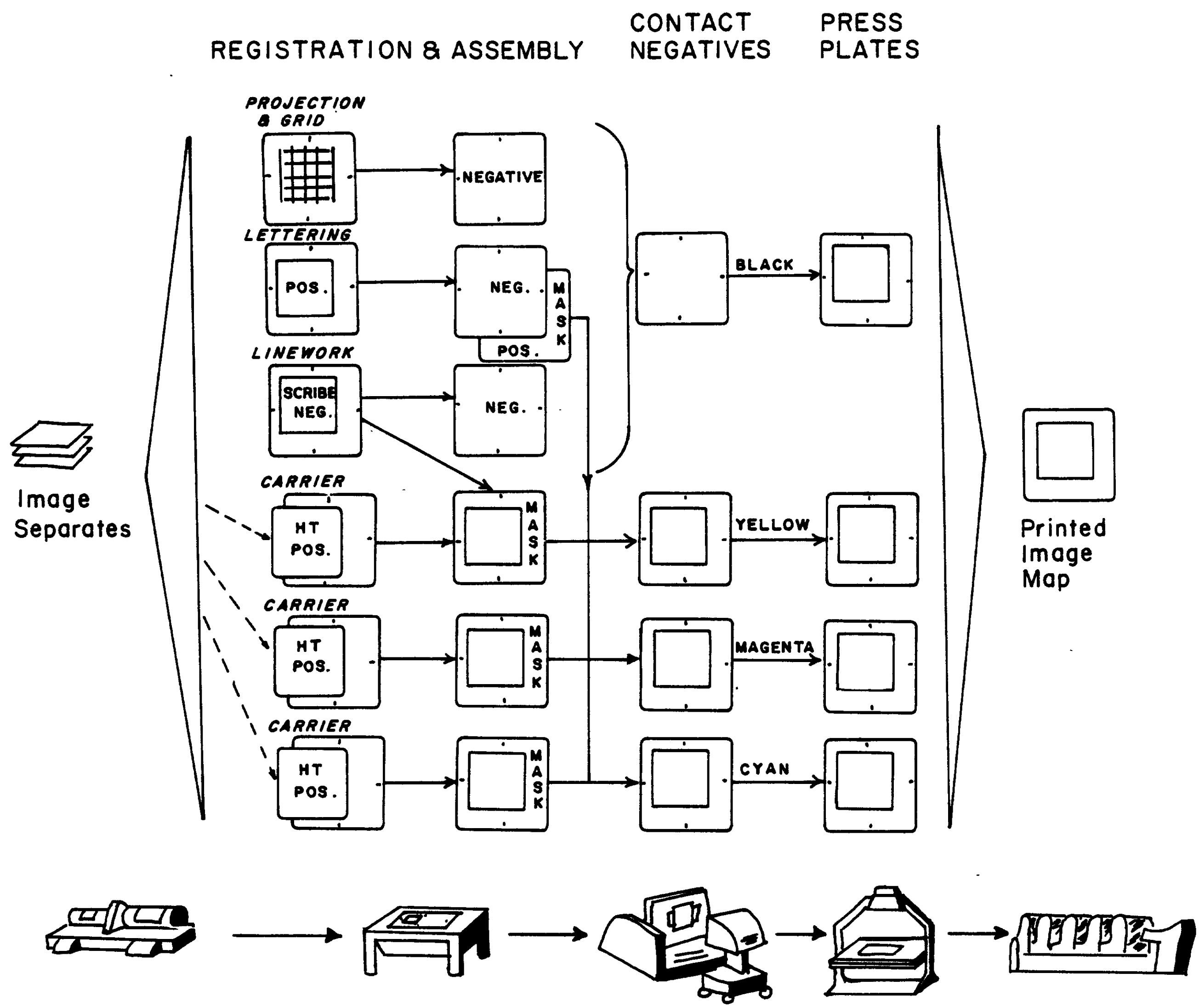


Figure 11. Graphic summary of the cartographic process in the preparation of the image map for printing.

<u>Registration and Assembly.</u> To assure consistency in the placement of each color separate and overlay material, a four-punch register system, such as the Alldis, is used in the registration and assembly operation. The layout sheet and every sheet used in the assembling of the contact negatives for platemaking are punched identically. First, one sheet of scribecoat material (yellow-coated plastic sheet) and four plastic sheets of 0.007-inch clear film are punched registered. The scribecoat is used as a border and linework overlay. Three of the clear plastic sheets serve as "carriers" for each halftone positive separate. Three additional carrier sheets may be needed if a side-panel image is included in the image map design. The remaining sheet of clear film is used as the lettering or names placement overlay. A computer-generated plot of the projection grid for the image map is punched after it has been registered with the master layout. During the

entire color separation and reproduction preparation cross registration checks are made to assure all sheets are in perfect register.

Once the border neatline and other designated "open-window" areas of the layout have been scribed (i.e., translucent emulsion is shaved away with a scribing tool to form transparent lines) on the yellow scribecoat sheet, three peelcoats (orange-colored plastic sheets) are reproduced from it to serve as open window "masks" for the yellow, magenta and cyan color separations. The masks protect film areas outside the borders from exposure during contact negative reproduction. During this time "stick-up" type (printed on adhesive-back transparencies) for the lettering overlay is acquired for later assembly.

In the assembly of the color separations, a prepunched clear-film sheet is registered to the linework overlay for mounting each halftone positive separate. The fourth prepunch clear-film sheet is registered to the master layout for type placement.

Once the lettering overlay is completed, a contact negative is made and stored with negatives of the linework, projection, and grid. Together they will be used for making the black press plate. In addition, a film positive of the lettering overlay is reproduced for use as a dropout mask (see fig. 11). The lettering film positive serves to drop out the image wherever a word is overprinted, thus resulting in white instead of black printed words. Other overprinting techniques which will not be discussed here (e.g. halo) are also used to improve the legibility of names in dark areas of images. Prior to using the lettering negatives, the words to be printed in black are opaqued on the negative prepared as the dropout mask, conversely the words to appear in white are opaqued on the negative to be used in making the black press plate.

The three mask peelcoats that were produced from the scribed linework overlay are prepared for assembly by peeling the common frames or open windows from each plastic coated sheet. The masks are overlaid individually on the yellow, magenta, and cyan color separates (contact negatives) in producing the press plates.

Geometric Accuracy Testing. A test for geometric accuracy of the separates is performed before platemaking to determine if the UTM grid and image are within National Map Accuracy Standards (NMAS). To meet National Map Accuracy Standards, which is defined by 90-percent-error or root-mean-square-error (RMSE) values, the image map separates should have less than the following errors:

Scale	90%		RMSE	
	feet	meters	feet	meters
1:100,000	166.1	50.6	101.4	30.6
1:250,000	413.0	125.9	251.8	76.7

A minimum of 20 well-distributed test points per image are selected from large-scale line maps and digitized for application of the H253 TRNSFORM program. The TRNSFORM program determines the horizontal RMSE of residuals between the true and observed values of the test points. Satellite image maps are generally within 2x NMAS, as a result of uncorrected systematic errors.

Contact Negative Preparation and Proofing. In developing "negative-working plates," it is necessary to convert photographically the assembled halftone positives to halftone negatives. During this operation, these halftone positive separates are overlaid emulsion-to-emulsion (image contact) with the negative film in a vacuum printing frame to obtain precise halftone dot duplication. Even though perfect contact is acquired, the resulting contact negatives will normally show a density or dot gain of about 5 percent that is due to light diffraction. This inexactness of the conversion of the halftone positives to halftone negatives is usually corrected when the positive pressplates are made. That is, when the contact negatives are converted back to positives on the pressplates, the 5 percent dot gain is lost. The USGS five-color press normally has very little true dot gain, yet the amount of actual dot gain on the printing of image maps, which is checked by a comparison of the density of the GATF dot gain scale on the pressplate with that of the printed sheet, may range from 3 to 7 percent per press unit. The gain in dot formation or density may stem from inaccurancies in exposures during proofmaking (T. Kiser, personal commun., 1984). To compensate for this anticipated dot gain, the halftone positives were sharpened by 5 percent during earlier scanner processing.

The projection/grid and lettering overlays are also individually vacuum contact reproduced. Each is composited with the scribed linework overlay on high-speed duplicating film in making the contact negative for the process black press plate. As previously discussed, a lettering dropout mask is assembled with each color separate in the conversion to press plates.

After the six contact negatives have been made ready, a Cromalin 4-color proof (yellow, magenta, cyan, and black) is prepared to evaluate the accuracy and quality of the registration and color, respectively (see earlier description on Cromalin preparation under "Color proofing"). Color proofing at this stage provides a means for catching mistakes before press plates are produced. A review of accuracy and internal registration of the assembled material is of considerable importance. For example, the image on the proof and the position of one color with respect to another must be correct. Reference controls such as a 21-step Stouffer continuous-tone density wedge and a 16-step screen tint scale are included in the color proof to monitor exposure and dot reproduction, respectively. Since the pigmented toners are made to match the offset press color inks, the Cromalin proof should be highly similar to the final printed image.

It should be noted that quality evaluation (as conveyed by the color proof) of the color separation and reproduction of an image map is highly subjective. The final assessment of whether the color proof is consistent with the criteria of informational content and interpretability that were established during digital processing, and whether it meets the desired perceptual appearance of the user, are problems of intuition and interpretation rather than just tasks of precise and faithful reproduction. Thus, experience and the knowledge of the image map's intent are key in the quality review of the color proof.

Platemaking

The platemaking operation is the next to the last step in converting the Landsat multispectral image into a printed form. The end products of this process are four-color pressplates ready for offset printing. A typical USGS preparation process would involve the following steps. First, a thin flexible finely-grained anodized aluminum plate is cleaned, treated and coated with a light-sensitive film. A halftone negative of the image (e.g., the TM band 1 and yellow combination) is then vacuum contacted with the coated surface of the plate and exposed by a controlled light source. The light that goes through the transparent part of the image hardens the coated plate surface and makes it insoluable. This insoluable surface of the image area or "photomechanic stencil" is developed to make it ink-receptive, while the soluable non-image area is treated to make it water-receptive. The greater the difference between the receptivity of the image and non-image areas to ink and water, respectively, the better the plates will run on the offset press. For purposes of discussion, platemaking is divided into two parts: (1) inspection and layout, and (2) photomechanical processing. Each part is summarized below.

Inspection and Layout. Upon delivery of the assembled halftone negatives and masks (commonly referred to as "flats" in lithography), all material is inspected for correct size, register provisions, and for error or defects. In addition, press gripper and trim allowances, plus ink and paper requirements are checked. Special image-map finishing specifications (folding, side panel images, etc.) are also reviewed for proper dimensional allowances. These checks may reveal a change in layout to conform with dimensional limitations of the printing press and to avoid specific press problems. After completion of the inspection and necessary adjustments are completed, the contact negative of the composited line, lettering and projection/grid overlays, (also referred to as the black printer) is marked with reference "lay" marks for the later positioning of the pressplate together with a pressplate clear-film template. This template, once aligned with the black printer, serves to register individually the other color separates to their respective press plates.

Photomechanical Process. The photomechanics of platemaking comprise three steps: plate coating, exposure, and development of the light-sensitive coating. To begin the operation, four pre-grained anodized aluminum plates, after being properly cleaned, are surface treated with a silicate compound. This is necessary because the diazo light-sensitive coating, which become ink-receptive when exposed to light, reacts with metal. The light-sensitive coating is applied with a simple two-roll coater device and is allowed to dry.

Once the four pressplates have been treated, coated, and dried, they are ready for exposure. The first plate is registered in a vacuum frame pressplate template and black printer. When the black printer is properly aligned and secured, the template is removed. A GATF color test strip is mounted on the trailing edge of the press plate outside the trim area alongside a Stouffer 21-step continuous-tone density wedge. The test strips enable the pressman to monitor various aspects of the printing process, including overall exposure, hues and densities of printed process inks; hues of the secondary colors, trapping and ink transparency; dot gain or loss; and deformation of halftone dots, such as may be caused by slur or doubling.

Exposure time in the vacuum frame is determined by the standards set by the manufacture of the diazo coating solution. The same general platemaking sequence used for the black printer, plus a mask overlay, is applied in making the yellow, magenta, and cyan pressplates.

After exposure, the pressplates are developed in an automatic plate processor. A quality control inspection is made of the pressplates for suitability of coating, dot size change, correct exposure, register, and completeness. If a change in coating sensitivity has occurred, the GATF test strip will show how much change has taken place and what caused the change. A plate that has been properly exposed and developed will normally show steps 1 to 5, or 1 to 7 as solid black on the Stouffer scale. If steps 5 or 7 are solid black, the succeeding steps will show as gray tone. These gray tones get weaker or lighter as the numbers go higher. In the Dyersburg (TM) and Las Vegas (MSS) experimental image maps, pressplate step 7 and step 5 respectively, showed as solid black.

Offset Printing

The printing of the multispectral image map is the last step in transforming the original satellite digital data to a printed image. This final phase of production is commonly referred to as presswork. Here lies the test of how well the previous generations of processing and reproduction were performed, as well as how well each component element in printing the final product was coordinated. The component elements of pressplates, printing inks, paper, and offset press, must be in tune or else all previous processing will have been in vain.

There are three primary steps in presswork as related to image map printing: (1) press preparation, (2) printing, and (3) finishing.

A brief explanation of the principle of offset or indirect printing is provided for those not knowledgeable about offset lithography. In offset printing the ink image from the press plate is not directly transferred to the paper, rather it is transferred to a synthetic rubber blanket cylinder (see fig. 12). The resultant reverse-reading image is printed on paper as the paper is pressed between the blanket and impression cylinder. The positive readable image of the press plate, which is easier to proof before use, is double reversed during transfer so that it reappears as a readable image on the final print.

There are numerous advantages for offset printing, two that are most-often mentioned are: (1) the blanket protects the plate giving it a longer life, and, (2) because the ink image is split twice, the final ink film is thinner and more conducive to faithful reproduction of fine details. (For more discussion of Offset Printing, see Strauss, 1967).

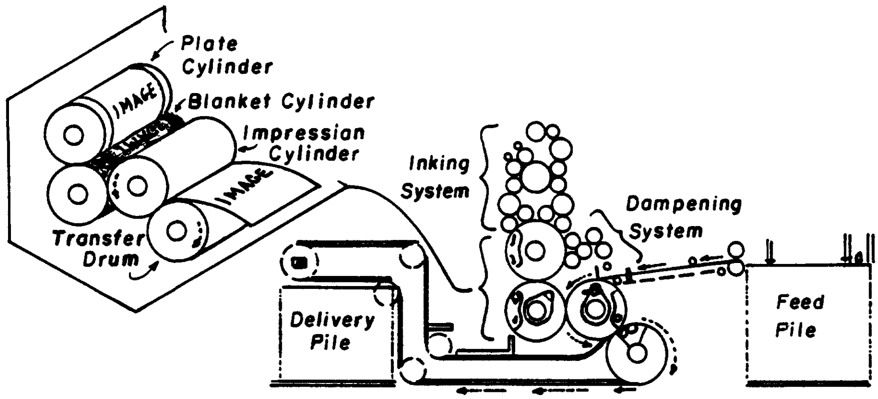


Figure 12. Schematic of tne lithographic offset press. (Adapted from the Lithographers Manual, 1974).

Press Preparation. After quality inspection of the pressplate indicates pressworthiness, job scheduling is set. Four of tne individual printing units of the USGS's 5-color sheet-fed Harris Offset press are made ready for the rinal printing of the image map. The pressman assigned to the job ("make-ready") is responsible for setting up the feeding, printing, inking and delivery units of the press according to the job record and specifications. This includes: (1) obtaining appropriate printing stock, (2) performing equipment operation checks of tne dampening and inking system, (3) packing of plate and blanket to required standards of each press station, (4) placing of inks in their proper printing sequence, and (5) registration and ink strength adjustment. Each of these steps is described more fully below.

To print the fine detail of an image map the pressman will assure that the printing stock nas a suitable surface. Dull-coated A260 paper stock is commonly prescribed for image maps because of its high printability and its superiority over otner paper for folding, brightness, opacity, tear resistance, and dimensional stability. Such paper, because of the ability to hold ink pigment on its surface, will print a solid ink density of up to 1.60 compared with about 1.20 for uncoated paper. This will allow a greater resolution and longer tone range between the highlight and snadow on the printed image. The pressman will normally make an equipment check to insure each press unit is functioning properly. One important check is of the inking and dampening units. The printing process makes more demands on its inking and dampening units tnan on any otner piece of equipment. Since the function of the inking unit is to provide the pressplate or "image carrier" with the proper amount of ink film, and the function of the water dampening unit is to provide the right amount of solution to the plate to insure that the non-image areas remain ink repellant, the pressman must maintain careful balance between them for good results.

For image maps at the USGS the ink printing sequence is black, cyan, magenta, and yellow. This generally calls for the placement of black in the ink feeder of the second printing station (the first station of the 5-color Harris Press is not used), cyan in the third, magenta in the fourth, and yellow in the fifth. The rationale for this sequence is based on the enhancement of registration, on the ink coverage on paper, and level of color transparency. The sequence is usually matched by a receding tack level. Tack or adhesiveness is essential for the transfer of the ink from roller to roller, then to the press plate, and onto the blanket and paper. Good "trapping" or acceptance of each successive ink overprint is imperative in the printing of multicolor images, therefore, the first ink usually has the most tack and each successive ink less. When a pressplate print results in a minimum amount of ink coverage on paper, the transfer of ink is even better, thus, promoting better trapping on successive overprints. This is why the black pressplate with its line and lettering data is inked first. Cyan is printed second because it is the least transparent and controls the contrast in density. Magenta and yellow follow in order of their increasing transparency

After all preliminary operations have been completed, the four mounted pressplates are brought into register. This is accomplished by the pressman first properly positioning the black plate and making prints of it. The remaining plates are then rotated to a position where they are in register with the black. The color proof is used as a guide for making comparison checks throughout this registration process. The pressman is responsible for improving or matching the registration of all colors with that of the proof. The last step in press preparation is setting the inking unit or "getting up to color." Getting up to color consists of adjusting the inks to the desired strengths. This operation cannot be completely divorced from the aforementioned registration process since the effectiveness of both operations cannot be judged until they appear as a printed image. Therefore, both may be dealt with simultaneously. The desired strengths of each ink is achieved by adjusting the inking unit of each station and running a few prints until a visual match is made with the color proof and a uniform density is obtained across the sheets. When the inking unit is fully adjusted, a sheet of the image map is printed for review and final approval of color and register. The mass production of the image map is only authorized after a satisfactory "press inspection" is completed.

Printing. Before the production printing of the image map, about 100 sheets must be run to get up to color again, after stopping for the "press inspection." Once the run begins, the primary responsibility of the pressman is to monitor the color evenness and registration of the printing to insure that no deviations occur from the approved copy guide. Quality control "press pulls" or printed samples are taken about every 10 minutes or 800 sheets to visually inspect for press problems. Reflection densitometers are used to supplement the visual inspection, and the results are documented for future reference and evaluation.

The press pulls should have standard density ranges as follows:

Press Station	Process Color	Reflection Density Range
1	None	None
2	Black	1.25 - 1.40
3	Cyan	1.20 - 1.30
4	Magenta	1.20 - 1.30
5	Yellow	0.81 - 0.89

When problems arise, the pressman makes the necessary adjustments to bring the printed image back up to standard. A production run may involve the printing of 1,000 to 4,000 image maps plus overruns on the first printing (Las Vegas and Dyersburg experimental image map printing amounted to 4,200 and 1,000 copies, respectively). A small number of overruns are made to compensate for press pulls and damaged sheets.

For experimental image map sheets that are accompanied by back-to-back printing of the standard USGS line maps of the same area and scale, such as Las Vegas and Dyersburg, the image map undergoes another printing sequence. After the sheets have dried for approximately 8 hours the entire stack of printed sheets is turned over for the printing of the line map on the unprinted side. The development of the line map follows standard map color separation and reproduction procedures. Press preparation for the line map printing is similar to the image printing with the exception of the mounting of an additional press plate and a different inking sequence -- red (road classification), blue (drainage), brown (contours), black (culture), and green (woods), respectively. Insofar as the make-ready and printing operations are concerned, the quality-control measures are similar to those used for image maps.

Finishing. After the printed sheet comes off the press, finishing can include trimming, inspecting, folding, inserting into envelopes, boxing, and delivery.

This final operation completes the satellite multispectral image maps cycle as practiced at the U.S. Geological Survey.

CONCLUSIONS

There are several new technological developments that are expected to improve the overall quality of image map products as well as reduce processing time and costs.

One development is the merging of image data from spaceborne electro-optical and photographic systems to produce high spectral and spatial resolution large scale image maps. Experimentation by the USGS in merging multisensor data from Landsat Thematic Mapper and photographs from the National High Altitude Aerial Photography (NHAP) program has already proven successful in generating high resolution image products at large scales. Also being tested is the merging of Landsat TM data and Large Format Camera photographs.

Another development is the replacement of the Navy Transit satellite system by the Navstar Global Positioning System (GPS) for establishing horizontal control for mapping. By the end of this decade, the GPS will consist of 18 satellite at 20,200 km altitude in six different orbital planes at 55 degree inclination with upload of ephemeris data and time every 12 hours. The completion of the GPS will considerably reduce the time and cost of establishing control and will be especially valuable to image mapping in unmapped areas of the world.

A third development is the recent launching of the SPOT land resource satellite with 10- to 20-meter resolution and stereoscopic capability. Although the value for topographic mapping is limited due to the geometric uncertainties involved in its non-continuous acquisition of the stereo data, its higher resolution capability will improve the quality of imagery at large scales.

Other developments will result from state-of-the-art advancement in the digital processing of satellite image data and space photographs. Some of the most important being (1) the final-scale map reproduction and separation of digital image data directly from magnetic tapes (see future process arrow in figure 8), (2) the refinement of computer techniques for digital mosaicking of satellite image data over large areas (in both latitude and longitude) and the extraction of the individual quadrangles for more efficient image map production, and (3) new techniques for merging satellite image data with conventional cartographic and natural resource data sets in digital form for rapid analysis and more timely and effective Earth resources assessment.

GLOSSARY OF KEY TERMS

The terms in this glossary are defined as they are applied to satellite image cartography. For further definitions see, The Manual of Remote Sensing (Reeves, 1975, p. 2061-2110), The Lithographers Manual (Shapiro, 1974, p. 17:1-15), Color Separation Techniques (Southworth, 1979), Glossary of Mapping, Charting, and Geodetic Terms (DMA, 1981), and the Dictionary of Scientific and Technical Terms (Lapedes, 1974).

ADDITIVE PROCESS: Pertains to the production of color by the superposition of the separate primary light colors of red, green, and blue. For example, red and green projected together produce yellow, red and blue produce magenta, and blue and green produce cyan.

AIMPOINTS: Selected points usually at the ends and middle of the the brightness value range used during contrast stretching of an image; in photomechanics, selected points along the characteristic curve usually at the highlight, middletone, and shadow.

CHARACTERISTIC CURVE: A curve plotted to show the relationship between exposure and resulting density in a photographic image, usually plotted as the density (D) against the logarithm of the exposure (log E) in candle-meter-seconds. Also called H and D curve and D log E curve.

COLOR SEPARATION: A photographic process or electronic scanning procedure using color filters to separate multicolored copy into separate images of each of the three additive primary colors (red, green, and blue). These separates, after pre-press preparation, can then be used to recreate the colors of the original image when printed in the substractive primary inks (cyan, yellow, and magenta).

CONTACT PRINT: A print made from a negative or a diapositive in direct contact with sensitized material.

CONTINUOUS TONE: An image which has not been screened and contains unbroken, gradient tones from black to white, and may be either in negative or positive form.

CONTRAST: Tonal comparison of the brightest highlights and deepest shadows in an original or reproduction. The tonal difference in detail, i.e., "contrasty" copy refers to accentuated detail in both highlights (light) and shadows (dark) areas.

CONTROL: A system of marks or objects on a map, photograph, or the Earth's surface, whose positions or elevation, or both, have been determined. Ground control points constitute the framework by which image map details are fixed in their correct position, azimuth, elevation, and scale with respect to the Earth's surface.

D-MAX: The highest density which can be obtained with a particular photographic material. When referring to a particular negative or positive, the highest density recorded. Also called Dx.

D-MIN: The lowest density on a positive or negative. Also called Dn.

DENSITY: A measure of the degree of blackening of an exposed film, plate, or paper after development, or of the direct image. It is defined strictly as the logarithm of optical density where the density is the ratio of the incident to the transmitted (or reflected) light. As density goes up, the amount of light reflected or transmitted decreases.

DIGITAL NUMBER (DN): An integer value related to the brightness (or intensity of radiation) for an area within an image. The value falls within a preselected range; for example, Landsat data are manipulated in eight-bit format, with values from 0 to 255. Also referred to as brightness value (BV).

ELECTROMAGNETIC RADIATION: Energy emitted as a result of changes in atomic and molecular energy states and propogated through space at the speed of light. Also called EMR and electromagnetic energy.

FILTERING: A technique that allows the enhancement of either large patterns (low-pass filtering) or detail (high-pass filtering) within a digital image.

GAMMA: Photographic term for negative contrast resulting from development of the photographic material and not the contrast of the subject itself. The numerical figure for gamma is the tangent of the straightline (correct exposure) portion of a characteristic curve resulting from plotting exposure against density. A negative which has the same contrast as the subject photographed has a gamma of 1.0.

GRADATION: In photographic originals and reproductions, the range of tones from the brightest highlights to the deepest shadows.

GRAY BALANCE: The maintaining of a neutral gray scale in a color reproduction by proper adjustment of the cyan, magenta, and yellow colorant amounts.

GRAY SCALE: A strip of standard gray tones, ranging from white to black, placed at the side of original copy during photography to measure tonal range obtained, and in the case of color-separation negatives for determining color balance or uniformity of the separation negatives.

HALFTONE: Any photomechanical printing surface and impression therefrom in which detail and tone values are represented by a series of evenly spaced dots of varying size and shape, the dot areas varying in direct proportion to the intensity of the tones they represent.

HISTOGRAM: A graphical representation or tabulation that summarizes the number of picture elements (pixels) occurring at each gray tone or digital number value within an image.

IMAGE ENHANCEMENT: Any of several processes that might improve the interpretation quality of an image. Such processes include contrast and edge enhancement, ratioing, spatial filtering, etc.

IMAGERY: Collectively, the representations of objects reproduced electronically or by optical means on film, electronic display devices, or other media.

LINES TO THE INCH: Crossline halftone screens are made up of opaque lines ruled at right angles to each other. Some screens have more or less lines to the inch than others and are accordingly classified. The 175-line screen is the most commonly used for the lithographic production of color image maps which require a very fine detail work screen. The number of dots to the square inch is the square of the lines to the inch of the screen; for example, the 133-line screen produces 17,689 dots per square inch.

LOOK-UP TABLE: Array of precalculated data arranged so that answers to multiplication, division, and other time-consuming computations can be obtained from the array by the use of indexing answers as a function of brightness value.

MIDDLETONE CONTROL: The use of a control step in the middletones to know when masks and separation negatives are properly made. The most common middletone control is an area that will print a 50% dot in the middletone of the magenta and yellow printer.

MOSAICKING: The assembling of images whoses edges are matched photomechanically or fitted digitally by computer to form a continuous image representation of a portion of the planet's surface.

MULTISPECTRAL IMAGERY: Images acquired simultaneously by a sensor system in a number of discrete bands in the electromagnetic spectrum.

NOISE: Spectral reflectance values that are not received from the target but rather introduced by the detector, by digital recording, and by data transmission, reception, and reduction instruments. Referred to as coherent noise which has a systematic pattern and random noise which has no pattern.

NEUTRAL GRAY: Any level of gray from white to black that has no apparent hue or color. Produced by printing proper amounts of cyan, magenta, and yellow colorants. For example, neutral gray might be produced by printing 65% cyan, 50% magenta, 50% yellow. Also referred as Equivalent Neutral Density (END).

PHOTOMECHANICAL: General term for any duplication process in which photography is employed in the production of a printing surface. The term emcompasses collotype, photoengraving, photogravure, photolithography, rotogravure, silk screen photostencil printing, etc.

PROCESS COLORS: Yellow, magenta (cold red), and cyan (blue-green), are the three process colors. They are so selected because when used in various strengths and combinations they make it possible to reproduce thousands of different colors including black with a minimum of photography, platemaking and presswork. The application of yellow, magenta, and cyan is referred to as the subtractive color process.

PICTURE ELEMENT (pixel): A digital representation of the electromagnetic radiation from the smallest area measured by the detectors. In black-and-white hard copy, the digital representation appears as a gray shaded square with the gray tone corresponding to the amount of radiation transmitted to that area.

RATIOING: The process of dividing each picture element (pixel) value in one image (or band) by the corresponding pixel digital number of another band.

RESOLUTION: The minimum distance between two adjacent features, or the minimum size of a feature, which can be detected by a remote sensing system. Also, defined as the ability of the entire electro-optical or photographic system to render a sharply defined image; it is expressed in terms of lines per millimeter or meters per pixel.

SATURATION: The condition in which a further increase in radiation produces no further increase in recorded radiation. Also defined as the degree of intensity difference between a color and an achromatic light-source color of the same brightness.

SPECTRAL SIGNATURE: The characteristics or patterns of physical features that permit objects to be recognized on remotely sensed imagery. The quantitative measurement of the properties of an object at one or several wavelength intervals.

STRETCHING: A computer technique for expanding the original range of digital values to utilize the full contrast range of the recording film or display device. Also called contrast stretching.

TOE: The portion of the characteristic curve below the straight-line section of the curve. It represents the area of minimum useful exposure.

TRANSPARENCY: An image fixed on a clear base by means of photographic, printing, chemical, or other process, especially adaptable for viewing by transmitted light.

U.S. NATIONAL MAP ACCURACY STANDARDS (NMAS): For horizontal accuracy maps at publication scales larger than 1:20,000, 90 percent of all well-defined features, with the exception of those unavoidably displaced by exaggerated symbolization, will be located within 1/30 inch (0.85 mm) of their geographic positions as referred to the map projection; for maps at publication scales of 1:20,000 or smaller, 1/50 inch (0.50 mm). For vertical accuracy, 90 percent of all contours and elevations interpolated from contours will be accurate within one-half of the basic contour interval. Discrepancies in the accuracy of contours and elevations beyond this tolerance may be decreased by assuming a horizontal displacement within 1/50 inch.

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