UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Enhancement of Landsat images for lineament analysis in the area of the Salina Basin, New York and Pennsylvania

by

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This report is preliminary and
has not been edited or reviewed
for conformity with U.S. Geological
Survey standards and nomenclature.

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ABSTRACT

Digital image processing of Landsat images of New York and Pennsylvania was undertaken to provide optimum images for lineament analysis in the area of the Salina Basin. Preliminary examination of Landsat images from photographic prints indicated sufficient differences between the spectral bands of the Landsat Multispectral Scanner (MSS) to warrant digital processing of both MSS band 7 and MSS band 5. Selective contrast stretching based on analysis of the Landsat MSS histograms proved to be the most important factor affecting the appearance of the images. A three-point linear stretch using the two end points and a middle point to the Landsat frequency distribution was most successful. The flexibility of the REMAPP image processing system was helpful in creating such custom-tailored stretches. An edge enhancement was tested on the MSS band 5 image, but was not used. Stereoscopic Landsat images acquired from adjacent orbits aided recognition of topographic features; the area of stereoscopic coverage could be increased by utilizing the precession of Landsat-1's orbit . Improvements in the digitally processed scenes did affect the analysis of lineaments for the New York area; on the enhanced MSS band 5 image, an ENE trending set of lineaments is visible, which was not recognized from other images.

INTRODUCTION

The U.S. Geological Survey is examining the relationship of regional lineaments visible on Landsat images to surface and subsurface structures as part of its program for geologic disposal of nuclear wastes. Previous studies have shown that regional lineaments are commonly not recognized during detailed geologic mapping, because they are typically morphologically complex and in some cases discontinuous; yet such features are commonly the surface expressions of extensive fracture and fault zones in the subsurface (Isachsen, 1973; Drahovzal and others, 1974; Cannich and Gold, 1977). Recognition of regional lineaments is therefore needed to help determine the structural framework of potential nuclear waste storage areas (Bredehoeft and others, 1978).

Computer processing of Landsat images is an essential part of the lineament analysis because no single image can portray all the information availible in the Landsat digital data. Digital image processing provides a means for selectively displaying the digital data in a manner best suited for a particular study. The goal of image processing described here is to enhance the topographic and tonal features that may constitute lineaments in the area of the Salina Basin, south-central New York and north-central Pennsylvania (fig. 1). The purpose of the paper is to describe the processing techniques used and to show how such techniques can alter the appearance of the image and affect the subsequent lineament analysis.

Figure 1 - Index map of the south-central New York and north-central Pennsylvania study area. Heavy solid line encloses area subset for testing different digital enhancements and is centered about the village of Van Etten, New York. Light solid line encloses area covered by the final appended Landsat images which include Landsat scenes 1459-15214 to the north and 1459-15221 to the south, both of 25 October 1973. The division between the two scenes is near Ithaca, New York.

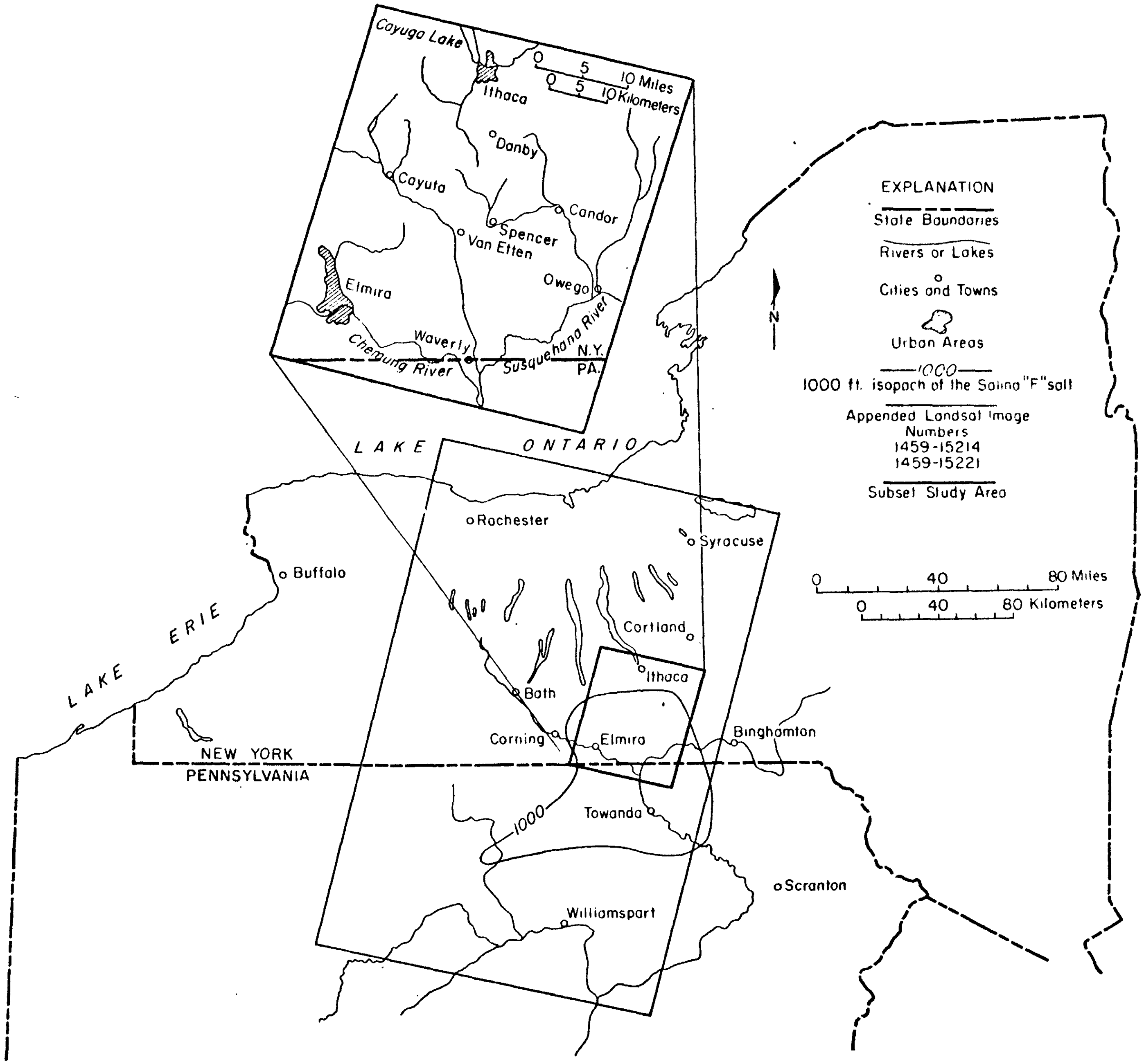
Cayuga Lake
Ithaca
0 5 10 Miles
0 5 10 Kilometers
Danby
Cayuta
Candor
Spencer
Van Etten
Owego
Elmira
Waverly
Susquehanna River
Chemung River
N.Y.
PA.
LAKE ONTARIO
EXPLANATION
State Boundaries
Rivers or Lakes
Cities and Towns
Urban Areas
1000
1000 ft. isopach of the Salina "F" salt
Appended Landsat Image
Numbers
1459-15214
1459-15221
Subset Study Area
N
Rochester
Syracuse
Buffalo
0 40 80 Miles
0 40 80 Kilometers
LAKE ERIE
Cortland
Ithaca
Bath
Corning
Elmira
Binghamton
NEW YORK
PENNSYLVANIA
1000
Towanda
Scranton
Williamsport

Fig. 1

GEOLOGIC DESCRIPTION

Rocks of the Salina Group in New York state are being evaluated for nuclear waste disposal because of the presence of thick salt deposits in the near subsurface (Brunton and others, 1978). The main depositional center for the Appalachian Basin of the Salina Group is located in New York and Pennsylvania. Salina rocks continue westward into Ohio and Ontario, and were perhaps connected by a seaway to the western Michigan Basin (Rickard, 1969). The Upper Silurian Salina Group in New York is composed primarily of evaporites, dolomites, and shales with the thickest aggregate salt deposits in the F unit outlined in figure 1. The F unit is between 500 - 1000 feet (150 - 300 m) below sea level at the southern end of the Finger Lakes and follows the regional dip to a depth of about 3500 feet (1050 m) below sea level at the Pennsylvania - New York border (Rickard, 1969).

Landsat images were selected to encompass the thickest part of the Salina Basin in New York (fig. 1). A smaller subset study area to test the image processing procedures was centered on three prominent lineaments that converge on the village of Van Etten, New York. Most of the area visible on the images is part of the Allegheny Plateau physiographic province, where the surface rocks are predominantly thin-bedded clastic sedimentary rocks of Middle to Upper Devonian age. The Plateau province is characterized by flat-lying rocks warped into broad open folds; their subsurface character is generally more complex. Pleistocene glaciations had a marked effect on the surface geomorphology; numerous examples of hanging valleys, drainage reversals, underfit streams, and other glacially related features are present in the region.

PHOTOGRAPHIC ENHANCEMENT

A practical first step to digital image processing is to preview the Landsat scenes of interest by photographic means. Photographic enlargments of Landsat negatives can be produced quickly and inexpensively; moreover, such hand-developed prints commonly show more detail with better tonal balance between images than the commercial prints availible from the EROS Data Center.

A set of 70 mm Landsat negatives was gathered to cover the entire northern Appalachian Basin. Low sun-angle fall and winter Landsat scenes were selected to highlight topographic details. The 70 mm Landsat negatives were enlarged to 11" x 14" prints at an approximate scale of 1:800,000. An enlargment of the Scranton-Binghamton MSS band 7 scene (scene no. 1080-15183) was used to test the lineament compilation procedures in the initial stages of the study (fig 2a). A mosaic of southern New York and northern Pennsylvania was made from eight 11" x 14" MSS band 7 enlargments. This uncontrolled mosaic was used to provide a preliminary regional geologic overview of the study area.

Differences between the MSS band 7 and the MSS band 5 photographic enlargments were sufficient to warrant computer processing of both bands for subsequent lineament analysis (fig. 2). Topographic features related to streams and stream drainage are highlighted in the MSS band 7 print (fig. 2a), which overall has greater contrast than the MSS band 5 print (fig 2b). Conversely, the flatter MSS band 5 image tends to subdue

Figure 2 - Comparison of photographic enlargments for (a) MSS band 7 and (b) MSS band 5, Landsat ID no. 1459-15221 of 25 October 1973. The photographic prints are enlargments of 70 mm negatives from the EROS Data Center, Sioux Falls, South Dakota.

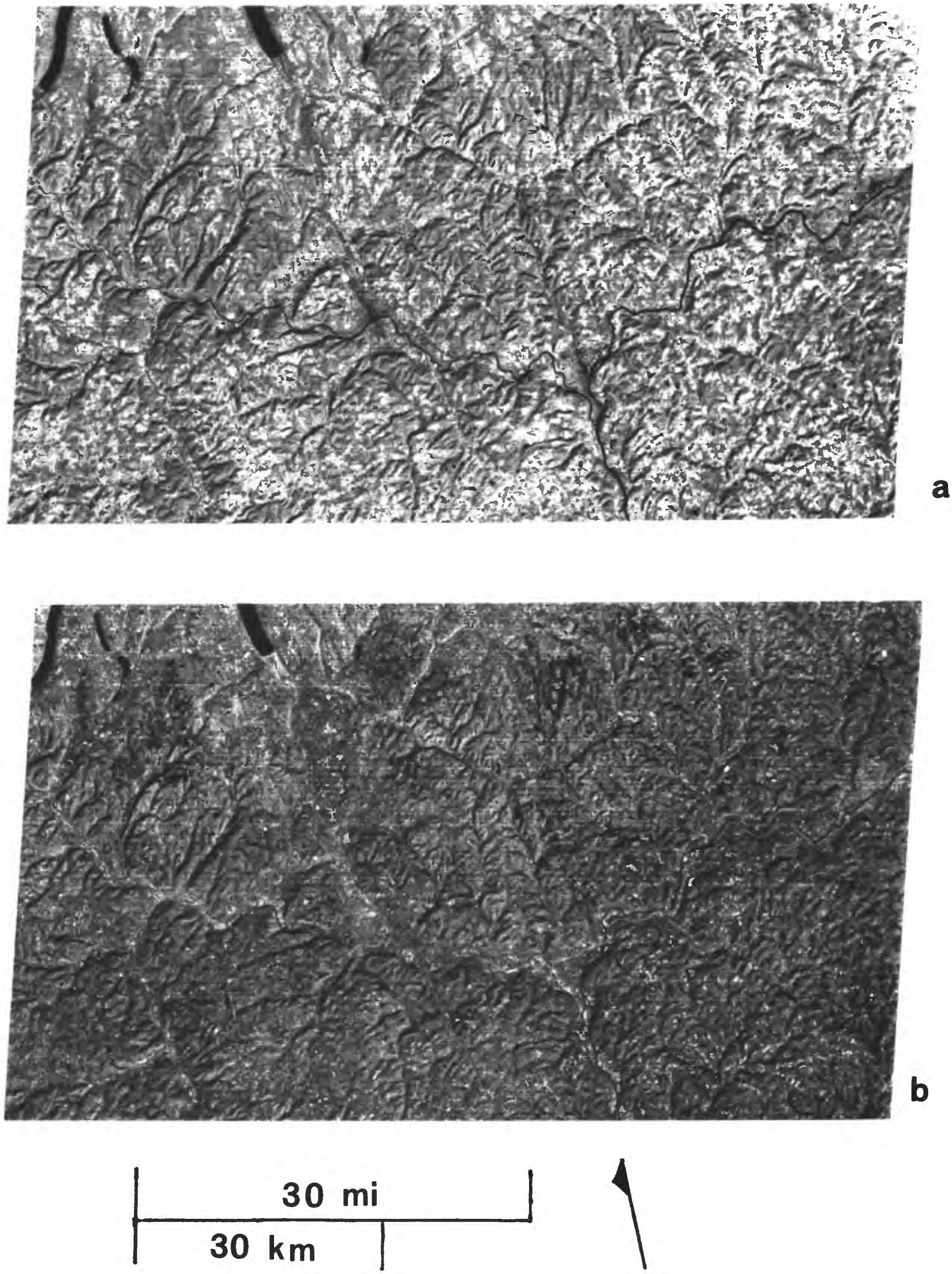

FIGURE 2

distinct topographic features but reveals more tonal detail resulting from forest cover and vegetation patterns, particularly in the upland areas of the dissected terrane. Because lineaments commonly arise from a variety of physiographic features, analysis of lineaments is facilitated if more than a single spectral band is used.

DIGITAL IMAGE PROCESSING

The Landsat Multispectral Scanner

Digital image processing refers to the computer processing of a large array of digital numbers (DN's) to form an image. This report will deal with digital numbers obtained by the Landsat Multispectral Scanner (MSS); however, the digital processing techniques described are also applicable to aircraft and other satellite scanners.

The Landsat MSS is an oscillating mirror-type scanner with four spectral bands (table 1). Six sensors in each of four bands are swept across in a single scan. Nominal resolution of a picture element (pixel) is 79 m. MSS bands 4 through 6 have 7-bit (0-127) radiometric resolution; MSS band 7 has only 6-bit resolution (0-63) (Taranik, 1978).

Landsat orbits the Earth in a near-polar orbit from north to south and scans a particular area on the Earth at the same local time every 18 days. Each day, the orbital track precesses to the west resulting in approximately a 10 percent sidelap of the image at the equator. For New York State, the mean crossing time for Landsat is 9:30 am and stereoscopic sidelap is approximately 30 percent. Landsat-1, launched in 1972, started to show some orbit decay by the summer of 1976. The mean crossing time

TABLE 1

Bandpasses for Landsat imaging systems

(after Taranik, 1978)

Sensor	Band Label	Type of Radiation	Wavelength (micrometers)	Comments
RBV	1	Yellow-green	0.475-0.575	functioned intermittantly
RBV	2	Green-red	0.580-0.680	on Landsat -1 and -2
RBV	3	Red-near IR	0.690-0.830	
RBV	*	Green-near IR	0.505-0.750	*Landsat-3 has only a single panchromatic band, so there is no band label.
MSS	4	Green	0.5 - 0.6	
MSS	5	Red	0.6 - 0.7	
MSS	6	Near IR	0.7 - 0.8	
MSS	7	Near IR	0.8 - 1.0	
MSS	8	Thermal IR	10.2 - 12.6	onboard Landsat-3 only; not currently functional

RBV = Return Beam Vidicon
MSS = Multispectral Scanner

became earlier, resulting in additional areas of stereo coverage (Taranik, 1978). Unfortunately by January, 1977, the MSS band 4 sensors failed, and on 6 January 1978, Landsat-1 ceased to operate.

Landsat-3 was successfully orbited in March, 1978 , and as of this writing is still being calibrated. The Landsat-3 MSS is similiar to its predecessors, except that an extra spectral band in the thermal region has been added. In addition the Return Beam Vidicon (RBV), a system that was intermittently operational on Landsat-1 and Landsat-2, is functional on Landsat-3 (table 1). The RBV is a sensor similar to a TV camera and has nearly three times the spatial resolution of the MSS (Colvocoresses, 1978; NASA, 1971).

Digital data from the Landsat MSS is obtained from the EROS Data Center as a computer-compatible tape (CCT). One Landsat scene is composed of 2340 scan lines, each consisting of 3240 pixels. The CCT is divided into four files, each comprising one-fourth of the image area. One file is 810 pixels wide by 2340 scan lines long, with all four bands interleaved. Identification and calibration data are contained in a header record at the beginning of each file.

Computer Equipment and Programs

Digital image processing at the USGS National Center is done on the Honeywell Multics 68/80 computer using the REMAPP image processing programs. REMAPP, an acronym for REMote sensing Array Processing Procedures, was developed by D.L. Sawatzky and T.E. Townsend, USGS Branch of Petrophysics and Remote Sensing in Denver, Colorado (Sawatzky and Townsend, 1976). The REMAPP programs are not confined to Landsat data, but are compatible with aircraft scanner or any digital data in array format.

A typical Landsat image-processing job at the National Center consists of four steps: [1] preliminary processing of tape data onto a disc pack; [2] calculating histograms for the frequency distribution of digital numbers for each spectral band; [3] developing an appropriate contrast stretch; and [4] making an output tape for playback onto film. A mountable disc pack with 35,779 pages of storage is used with REMAPP to accommodate the large amount of data. One page of disc storage on the Multics computer equals 1024 4-byte words. One MSS band for a single Landsat frame requires 7403 pages of storage with unpacked data or 1857 pages with packed data. Most of the preliminary work on the Landsat scenes is done with half frames to save storage and processing costs. Half frames are played back at pixel sizes of 100 micrometers, which requires a 2x digital enlargement to be compatible with the film-playback equipment at the National Center. Four to six half frames can by played back on one piece of film to expedite evaluation of the images. Standardized sets of instructions, known as absentee segments, were developed to handle most of the digital processing chores during off-peak hours.

Film Playback

Images are produced from the digital tapes at the National Center using an Optronics P-1700 Photomation system. (1) The Optronics system consists of a tape-drive, teletype, mini-computer, and Mark II Photomation, a combination of a rotary drum scanning microdensitometer and film-writer.

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(1) Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Digital numbers on the magnetic tape are converted to an analog signal which modulates a light-emitting diode (LED) light source. The LED can expose a range of 256 possible gray levels from digital numbers on the magnetic tape. Film is loaded in a mountable drum cassette, and the maximum film writing area is 23 cm x 23 cm. At the National Center, the pixels can be written in three sizes: 12.5 um, 25 um, and 50 um. Precision of spot-to-spot positions of pixels is equal to 2 um; accuracy to any spot on the film is 10 um.

Certain transformations of the digital data can be performed directly by the Optronics system as the film is being written. The choice of a direct or inverted transfer of the tape data is given for every image processed; Landsat and Optronics have opposite sign conventions so that an inverse transfer is required to produce a positive Landsat image. The transfer characteristic (TC) is an optional tranformation that converts digital data from the tape to specific output gray levels on film. Such transfer characteristics can be produced directly by a program in REMAPP and read into the Optronics by means of a paper-tape.

Kodak 2476 Linagraph Shellburst Film (Estar AH base) in sheets 25.4 cm x 25.4 cm is used to record images from the Optronics. Shellburst film is used because it has an extended density range and high resolving power. At the National Center, the film is developed using Kodak D-19 developer at 68 degrees F (20 degrees C) in a drum with continuous agitation. A development time of 2.5 minutes gives the most satisfactory film contrast and results in a gamma or slope of the characteristic curve of 1.6 (fig. 3).

Figure 3 - Characteristic curves for Kodak 2476 Linagraph Sellburst film. Film was developed in a rotating color drum using D-19 developer at 68 degrees Farenheit (20 degrees C) for varying lengths of time. A development time of 2.5 minutes yields the most satisfactory contrast and results in a gamma of approximately 1.6.

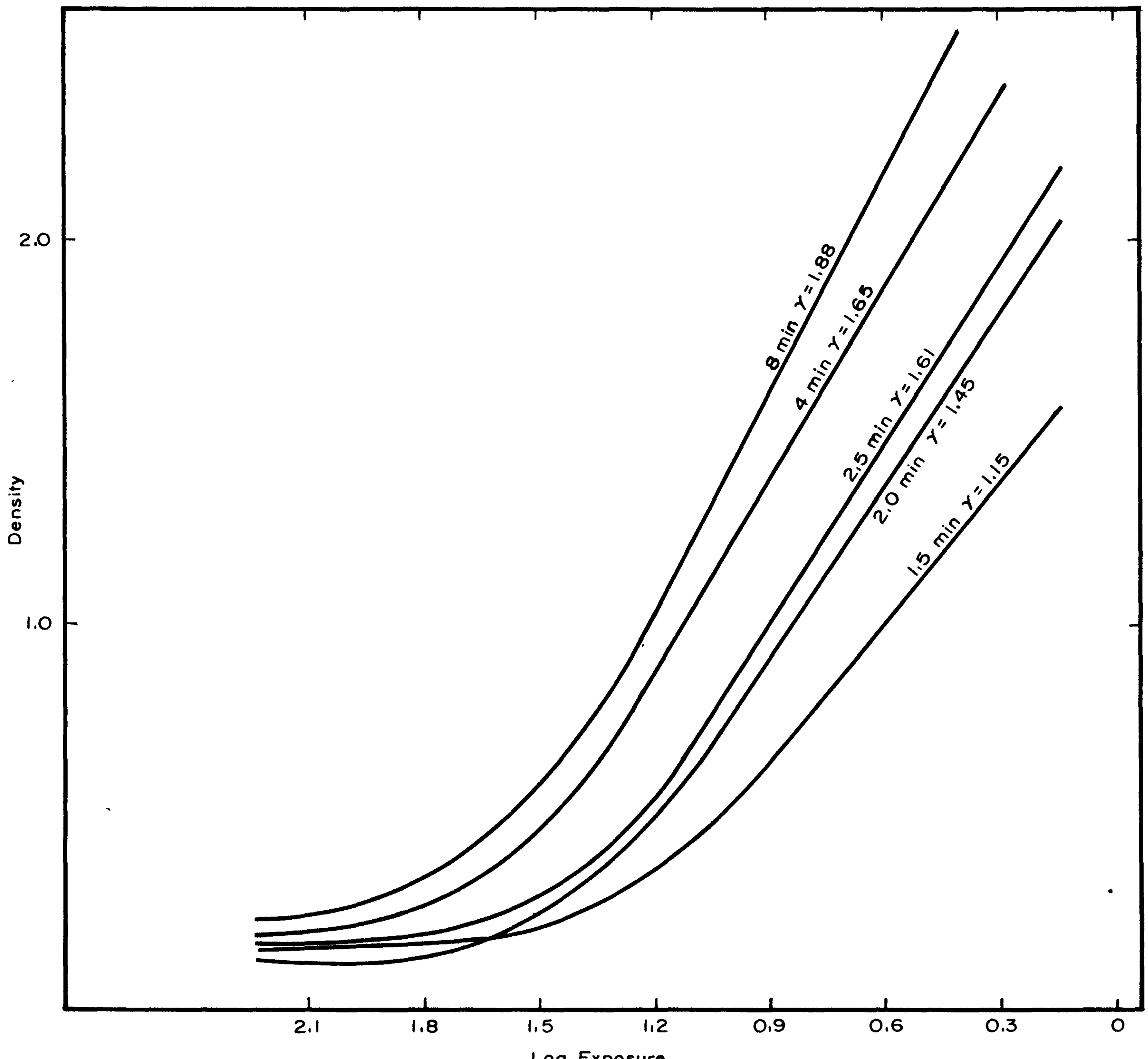
2.0
1.0
Density
8 min γ = 1.88
4 min γ = 1.65
2.5 min γ = 1.61
2.0 min γ = 1.45
1.5 min γ = 1.15
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
Log Exposure

Fig. 3

IMAGE ENHANCEMENT

Image enhancement is the selective transformation of radiance data from the Landsat MSS or other scanner to gray levels on film. Useful enhancements commonly include contrast stretching, destriping, and edge enhancement. Contrast stretching is the process of expanding the scanner radiance values to fit the range of the film playback device. Commonly the radiance values at the extreme low and high ends of the frequency distribution are compressed into a single minimum or maximum gray level on film, a process referred to as saturation. Such compression of the end points permits the expansion of the middle radiance values over a larger range. A commonly used contrast stretch has a 2 percent saturation, which implies that one percent of the low radiance values and one percent of the high radiance values are compressed to the minimum and maximum film density levels, i.e., black and white, respectively.

Analysis of Histograms

To summarize the more than 30,000,000 digital numbers (DNs) in one Landsat scene, some type of frequency distribution must be constructed. A frequency distribution can be mathematically represented as a probability density function or graphically presented as a histogram (Goetz and others, 1976). In REMAPP, the shape of the histogram is used to select the contrast stretch to be applied to the particular Landsat scene.

A sample set of histograms for the Finger Lakes area (fig. 4) illustrates some characteristic features of Landsat histograms. The histograms are in the range of DN 0-127 for MSS bands 4-6 and from DN 0-63

Figure 4 - Histograms of the four Landsat-1 MSS bands for the Finger Lakes region:

4a - MSS band 7

4b - MSS band 6

4c - MSS band 5

4d - MSS band 4

Data sampled is from the eastern half of scene 1459-15214 acquired 25 October 1973. The lower mode of the bimodal MSS band 7 and MSS band 6 histograms corresponds to water and results from the large number of lakes present in the scene.

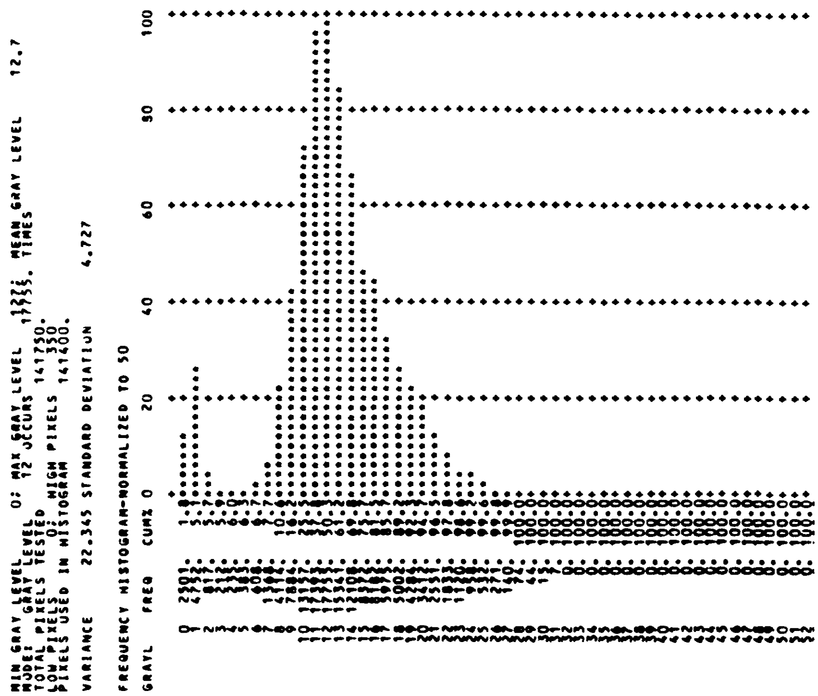

Figure 4a MSS Band 7

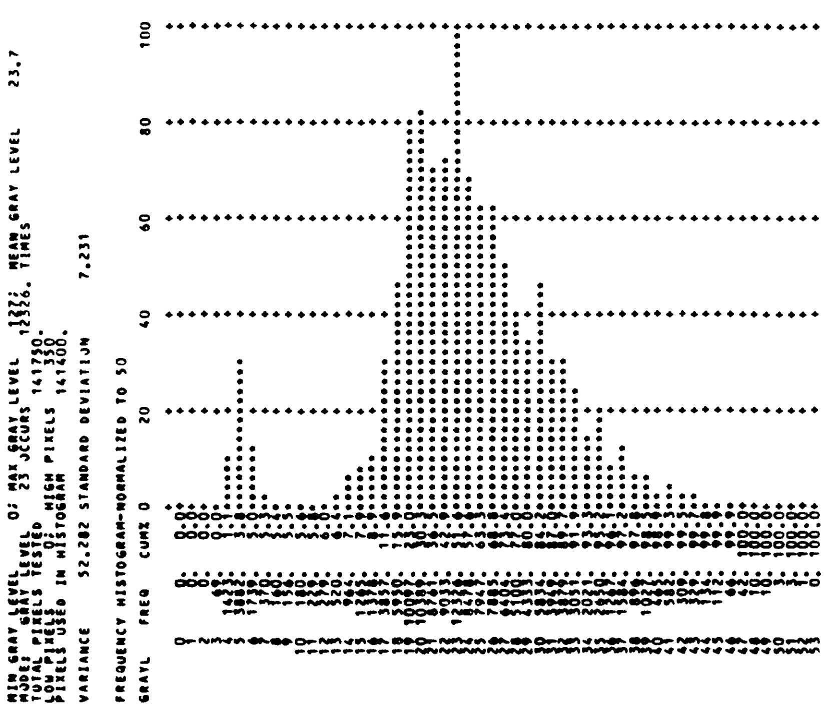

Figure 4b MSS Band 6

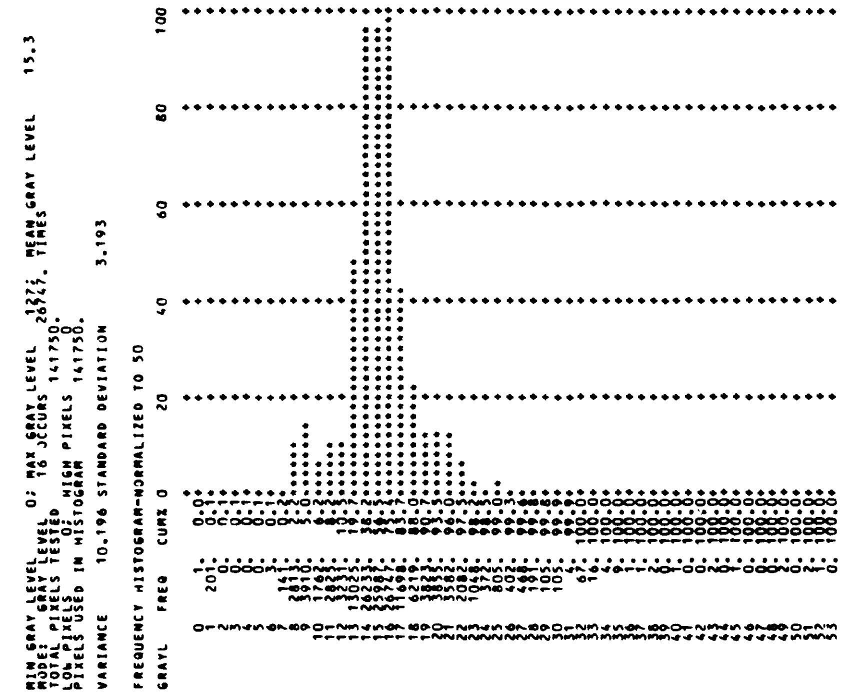

Figure 4c MSS Band 5

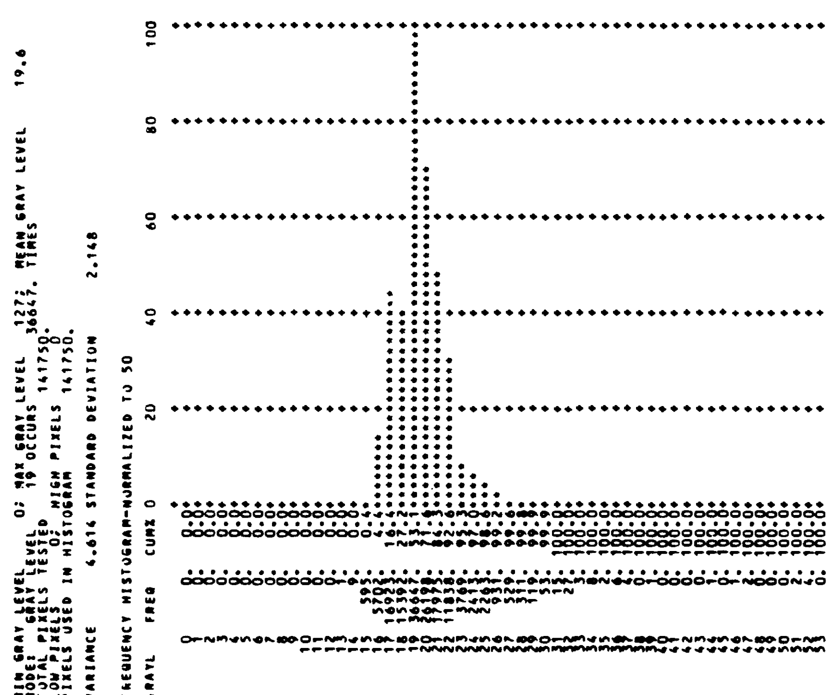

Figure 4d MSS Band 4

for MSS band 7. Low DN values correspond to areas returning a low percentage of incident energy or dark areas on a positive image; high DN values correspond to areas of high reflectance or bright areas on the image. Some specular reflectors on the ground can saturate the sensor to the maximum DN value; however, the range of DNs for a scene commonly spans only a fraction of the total range for the MSS. The maximum DN for the Landsat-1 images of New York is commonly about 30.

Histograms of Landsat data in many cases approximate a normal distribution; those histograms that are asymmetric tend to be positively skewed with a long tail toward the higher DN values. The histograms for MSS band 7 and MSS band 6 of the Finger Lakes area (fig. 4a and 4b, respectively) are bimodal. The lower peak corresponds to the low reflectance of water, whereas the higher peak represents the reflectance for land and vegetation. The histograms for MSS band 5 and MSS band 4 (fig. 4c and 4d, respectively) are more peaked with a smaller range of DN values than for MSS band 7 and MSS band 6. Peaked Landsat frequency distribution indicates a scene with low image contrast. Spikes in the Landsat histograms are not unusual and may result from radiometric calibration problems or may be an artifact of the digitization of the analog signal (Thomas, 1977).

Contrast Stretches

The REMAPP image-processing programs allow the user great flexibility in designing custom-tailored contrast stretches. The two programs that calculate the contrast stretches, TABLE and STRETCH-MAIN, utilize a table look-up algorithm: in this type of programming construction there is a one-for-one assignment of an input DN value to every output DN value for the film recorder. Thus the user can specify any discrete transformation from the input DN value to any output DN value. The most common transfer functions used for contrast stretches are linear stretches, logarithmic stretches, stretches based on the normal distribution, and cumulative density function (CDF) or ramp stretches. However, other arbitrary transfer functions can be created in addition to those mentioned above.

From past experience linear stretches have been an effective contrast stretch for the Landsat MSS images (Rowan and others, 1974). Such stretches are implemented by setting saturation levels for the two end points of the DN frequency distribution and expanding the middle DN values. Increasing saturation levels has two effects on the image: more pixels become totally white or totally black, and the density contrast of the image increases.

The relationship between image density, contrast and saturation levels is illustrated by plotting a graph of input DN (DNin) vs. output DN (DNout) (fig. 5). For a linear contrast stretch, the graph of DNin vs. DNout will be a straight line (fig. 5a). The slope of the line is proportional to the contrast of the image; in figure 5 the flatter the slope, the higher the contrast. Saturation is represented by the offset from the origin and by the maximum DN value along the ordinate (fig. 5a). An alternate way of describing a linear stretch is to use the form of a linear equation, $y=mx+b$, where m is the slope or gain and b is the offset.

More control over a linear contrast stretch is possible if a third point is specified between the two end points of a linear stretch. Such three-point linear stretches are represented graphically by a bisected line

Figure 5 - Schematic diagram showing the effects of different linear contrast stretches upon a hypothetical frequency distribution of Landsat DN values. Left side of the figure shows a graph of the input Landsat DN values (ordinate) versus the DN values output to the film recorder (abscissa) -- DNin versus DNout. The range of input Landsat DN values is much less than the range of output values availible on the film recorder (0-255). The slope of the line on the DNin versus DNout graph is a expression of the contrast of the image. Right hand side of the figure shows hypothetical Landsat histograms after contrast stretches have been applied. In this case, the hypothetical unstretched Landsat histogram is positively skewed toward the low DN values.

Figure 5a - Linear Stretch - The two end points of the DN frequency distribution are specified and the middle values in between are expanded equally. Saturation is the percentage of pixels made totally light or dark. Saturating more pixels flattens the slope on the DNin versus DNout graph and results in an image with greater contrast.

Figure 5b - Three Point Linear Stretch - The end points and a middle point for the Landsat distribution are specified. This type of linear stretch is commonly used with REMAPP; for example, the MSS band 7 image of New York. Different input DN values are used for the middle point to lighten or darken the image without changing the saturation. Substituting different input DN values for the middle point of a three point stretch will cause the inflection point on the DNin versus DNout graph to move vertically parallel to the DNin axis (ordinate). Using a higher input DN value (dashed line) forces more pixels below the mid-gray level and thus darkens the image.

Figure 5c - Skewed Three Point Linear Stretch - The two end points and a third point of the Landsat distribution are specified, but the third point is shifted away from the mid output DN value of 127 to a higher or lower output DN value. For the MSS band 5 image of New York, the inflection point was shifted from 127 up to a DN value of 180. The skewed three point linear stretch was used with MSS band 5 scenes to increase the contrast of the middle tones without oversaturating the light pixels.

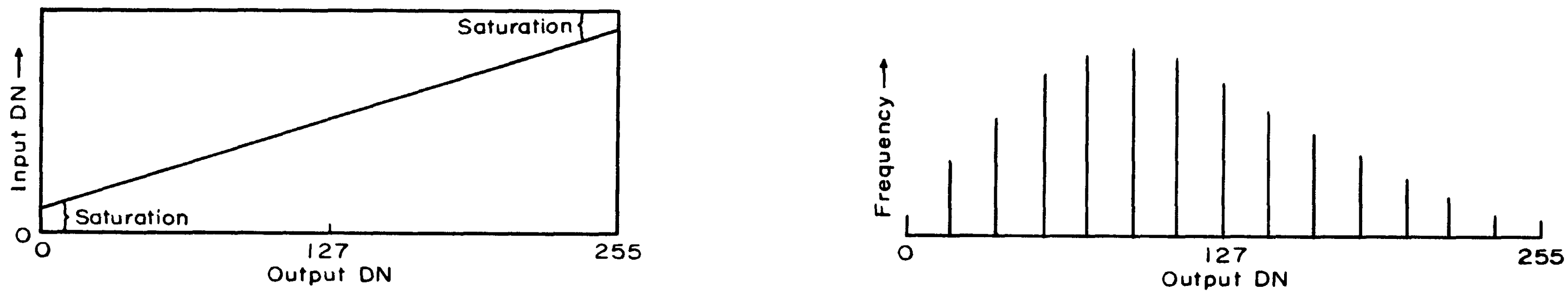

Figure 5a

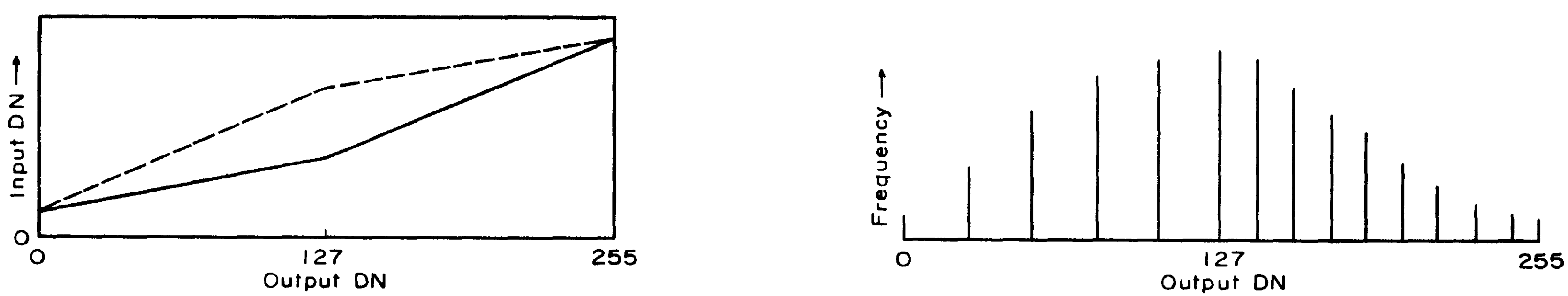

Figure 5b

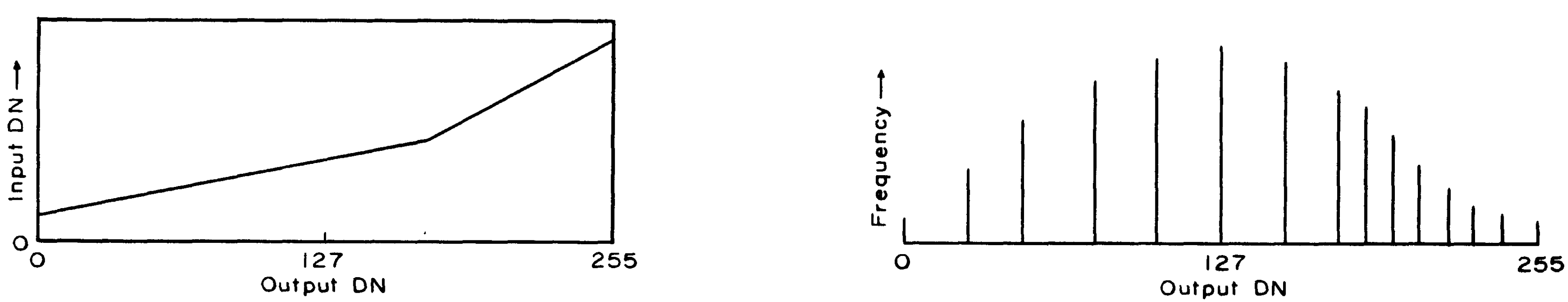

Figure 5c

with different slopes (fig. 5b). The third point of the contrast stretch is represented by the inflection point of the graph and is typically situated at the output mid-gray level of DN 127. Three-point linear stretches are more flexible than two-point stretches, because the overall density of the image can be adjusted without changing the saturation levels. The image is lightened or darkened by changing the input DN value used as the middle point of a three-point stretch; using a higher input DN for the middle point forces more pixels below the output mid-gray level and hence darkens the image (dashed line, fig. 5b).

A modification of the three-point linear stretch is to shift the third point away from the mid output gray level (fig. 5c), so that distinct portions of the DN frequency distribution are preferentially enhanced. The two different slopes shown in the graph of a three-point stretch (fig. 5c) represent two separate linear transformations applied to a single Landsat distribution. The difference in contrast levels can be utilized to redistribute strongly skewed or peaked distributions. For a positively skewed frequency distribution, such as MSS band 5 (fig. 4c), the third point of a three-point stretch is moved to a higher output DN level. Such action results in DN values below the shifted point having a greater contrast separation, whereas the higher DN values on the tail of the distribution are relatively compressed.

Application of Contrast Stretches

Band 7. Four different saturation levels of a linear stretch were applied to MSS band 7 data for an area surrounding Van Etten, New York (fig. 6). The percent saturation, as expressed here, is cumulative,

Figure 6 - Comparison of four saturation levels used with a linear stretch of MSS band 7 image, Landsat ID 1459-15221. The actual numbers used for the contrast stretch are given in the table below. Linear stretches are annotated in this report by giving the end points and the inflection points of the linear stretch as represented by the diagrams in figure 5. In figure 6b, for example, the Landsat DN of 1 (DNin) is transformed to a value of 0 for the film recorder (DNout), the Landsat DN of 12 is transformed to a value of 127 - the mid-grey level of the film recorder - and the Landsat DN of 25 is transformed to 255 for the film recorder. Linear interpolations are perfomed between these values when the contrast stretch is calculated. Such a contrast stretch results in a 2% saturation (sat.) for the image. The Landsat histogram for the above scene is shown in figure 4a.

Fig. 6a
(1% sat.)

DNin		DNout
0	=>	0
12	=>	127
26	=>	255

Fig. 6c
(3% sat.)

DNin		DNout
3	=>	0
12	=>	127
24	=>	255

Fig. 6b
(2% sat.)

DNin		DNout
1	=>	0
12	=>	127
25	=>	255

Fig. 6d
(4% sat.)

DNin		DNout
4	=>	0
12	=>	127
23	=>	255

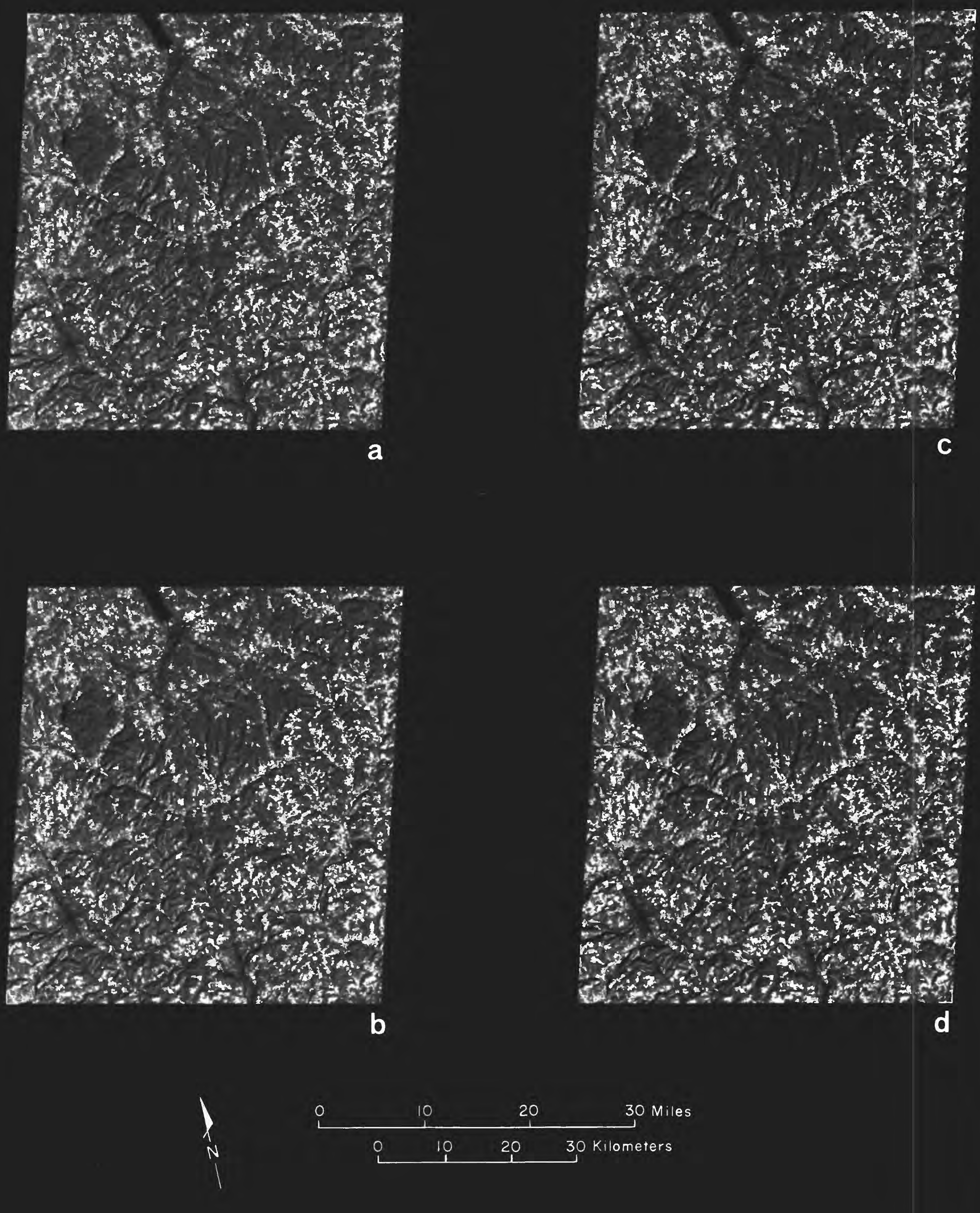

FIGURE 6

because the saturation levels were symmetric for both the dark and light ends. The most apparent effect of increasing the saturation (fig. 6a-6d) is to increase the overall contrast of the image. The increase in the number of saturated pixels is less obvious, but is somewhat apparent within the dark gray levels. Note the change from figure 6a-6d for the town of Elmira, New York at the southwest corner of the image, and the drainage just south of the tip of Cayuga Lake at the northern edge of the scene (fig. 1). For the final appended image product (fig. 11), a three-point stretch was used with the dark end saturation of figure 6d combined with the light end saturation of figure 6b.

Comparison of Landsat histograms from successive scenes in the same orbit illustrates the problem of applying linear contrast stretches based only on percent saturation. An MSS band 7 histogram of scene 1459-15214 to the north (fig. 4a) has a second mode in the low DN values due to the presence of large bodies of water, such as the Finger Lakes. This mode is absent in the histogram of scene 1459-15221 to the south (fig. 7). A DN value of 4 for the southern scene corresponds to a cumulative percentage of 1.3, but for the northern scene equals a cumulative percentage of 6.4. For lineament analysis, all the dark pixels of water were saturated, resulting in large lower saturation levels for some scenes.

<u>Band 5.</u> Digital image processing for the MSS band 5 image of south-central New York was undertaken because of the differences between the preliminary MSS band 7 and MSS band 5 prints (fig. 2). Development of a suitable contrast stretch for the MSS band 5 image was more difficult, because MSS band 5 is more subject to haze and commonly has a smaller dynamic range than MSS band 7 (fig. 4). An initial attempt to apply a

Figure 7 - Histogram of MSS band 7 for scene 1459-15221. Water mode is virtually absent in this histogram in comparison to the histograms for the scene to the north (fig. 4). Both scenes were acquired the same day.

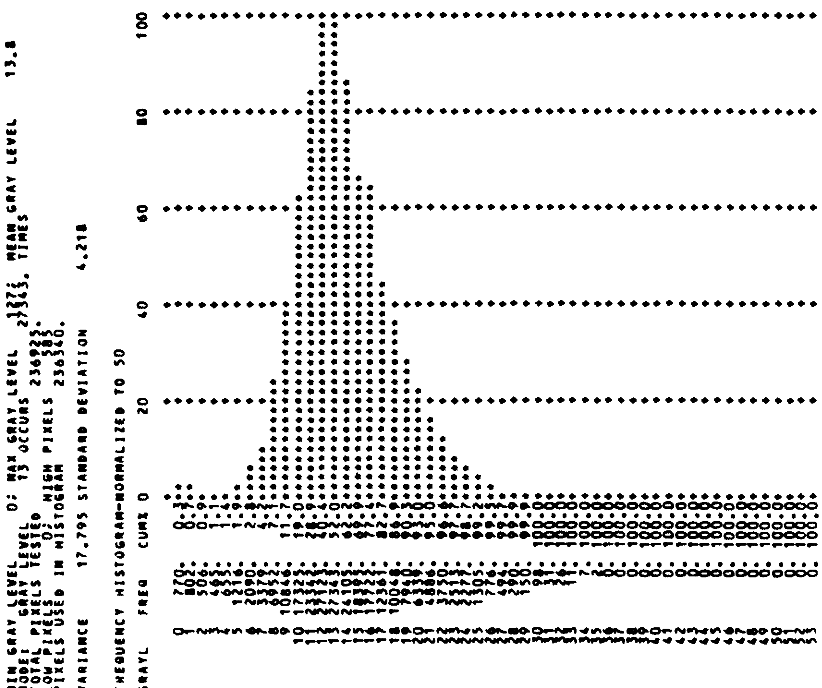

Figure 7 MSS Band 7

linear contrast stretch to the MSS band 5 image was unsatisfactory; the image appeared oversaturated in the light end, but lacked sufficient density contrast in the dark and mid-gray tones to define topographic features clearly.

Several different configurations of a three-point stretch (fig. 5) were successively applied to the MSS band 5 image in order to improve the tonal balance. In the first four attempts (fig. 8), the saturation of the two end points was held constant. The middle point was fixed at the output mid-gray level of 127. Four different input Landsat DN values were successively tried as the value for the middle point of the three-point stretch. The effect of using higher input DN values as the middle point (fig. 8a-d) is to make the overall image appear darker and to increase the contrast of the lighter pixels. The problem with this type of three-point stretch is that the mid-gray tones of the MSS band 5 image still seem to lack adequate gray-level separation for the resolution of topographic details.

A skewed three-point stretch (fig. 5c) was tested on the MSS band 5 image to improve the density contrast of the mid-gray pixels. In a skewed three-point stretch, the middle point is not fixed at the output mid-gray level of 127; rather, it is placed at some arbitrary output gray level between 0-255. For the MSS band 5 contrast stretch, the middle point was assigned an output gray level of 180. The effect of assigning a value of 180 to the midpoint is to expand the greater density separation of the dark pixels to more pixels in the mid-gray range, and concurrently to compress the density separation between the light pixels without increasing the saturation of the light end (fig. 5c).

Figure 8 - Comparison of four DN values used as a middle point of a three point linear stretch for an MSS band 5 image, Landsat ID 1459-15221. Saturation levels were held constant. See figure 4c for the relative position in the MSS band 5 histogram for the following four middle DN values:

Fig. 8a

DNin		DNout
9	=>	0
13	=>	127
27	=>	255

Fig. 8c

DNin		DNout
9	=>	0
15	=>	127
27	=>	255

Fig. 8b

DNin		DNout
9	=>	0
14	=>	127
27	=>	255

Fig. 8d

DNin		DNout
9	=>	0
16	=>	127
27	=>	255

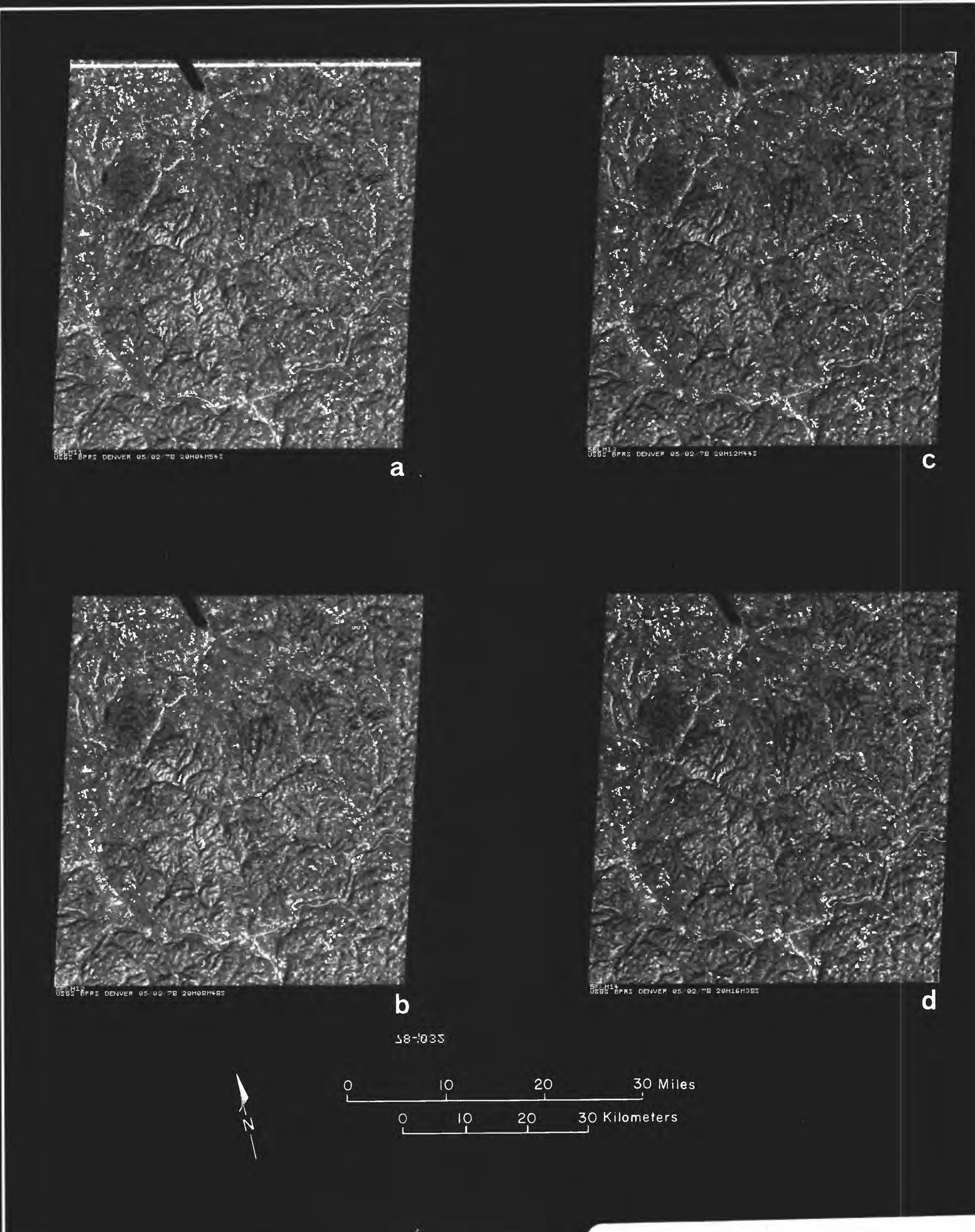
5ELM11
USGS BPRS DENVER 05 02 78 20H04M54S
a
5ELM13
USGS BPRS DENVER 05 02 78 20H12M44S
c
USGS BPRS DENVER 05 02 78 20H08M48S
b
USGS BPRS DENVER 05 02 78 20H16M38S
d
N
0
10
20
30 Miles
0
10
20
30 Kilometers

FIGURE 8

The results of the skewed three-point stretch are compared to three other contrast enhancements in figure 9. The increased mid-gray level separation of the skewed three-point stretch (fig. 9b) brings out more topographic and tonal detail in comparison to the other two linear stretches (fig. 9a and 9c). The compression of the light pixels that results from the skewed three-point stretch (fig. 9b), moreover, does not seem to have an adverse effect on the image. For comparison, a non-linear contrast stretch was applied to the MSS band 5 image (fig. 9d). AUTOTC is the name of a program within REMAPP that calculates a contrast stretch based on the cumulative frequency function of the normal distribution. The resultant image (fig. 9d) is darker and has a higher contrast than the other images, and overall, does not appear as suitable for the interpretation of lineaments.

Contrast stretches are the operation in image processing that probably has the largest effect on the final appearance of the image. Because of the variability of Landsat data, the user must analyze certain features of the DN frequency histograms to obtain the optimal stretch for each image. Such features include shape, symmetry, skewness of the frequency distribution, and the presence of second and third modes. REMAPP, because of the flexibility of its contrast stretch programs, is well suited for individualized stretches. A three-point contrast stretch seems to give the user good control over density and differential enhancement of the image. To apply effectively a three-point stretch, however, requires a sound understanding of the relationships between saturation, contrast, and placement of the middle point.

Figure 9 - Comparison of four contrast stretches used to implement better separation of mid-gray levels on the MSS band 5 image, Landsat ID 1459-15221. Three stretches are linear stretches and the fourth stretch is a non-linear stretch based on the normal distribution:

Fig. 9a

DNin	DNout
9	0
15	127
27	255

Fig. 9c

DNin	DNout
9	0
15	127
25	255

Fig. 9b

DNin	DNout
9	0
18	180
27	255

Fig. 9d

DNin	DNout
-	-
AUTOTC	
-	-

Figure 9a has the same stretch as figure 8c. Figure 9b is a skewed three point linear stretch, where both the input DN and the output DN have been moved relative to the Landsat distribution as illustrated by the schematic diagram (fig. 5c). In figure 9c, the upper saturation level is increased, but the other two values of the three point stretch remain the same. Figure 9d is the normalized contrast stretch calculated by REMAPP in the program AUTOTC.

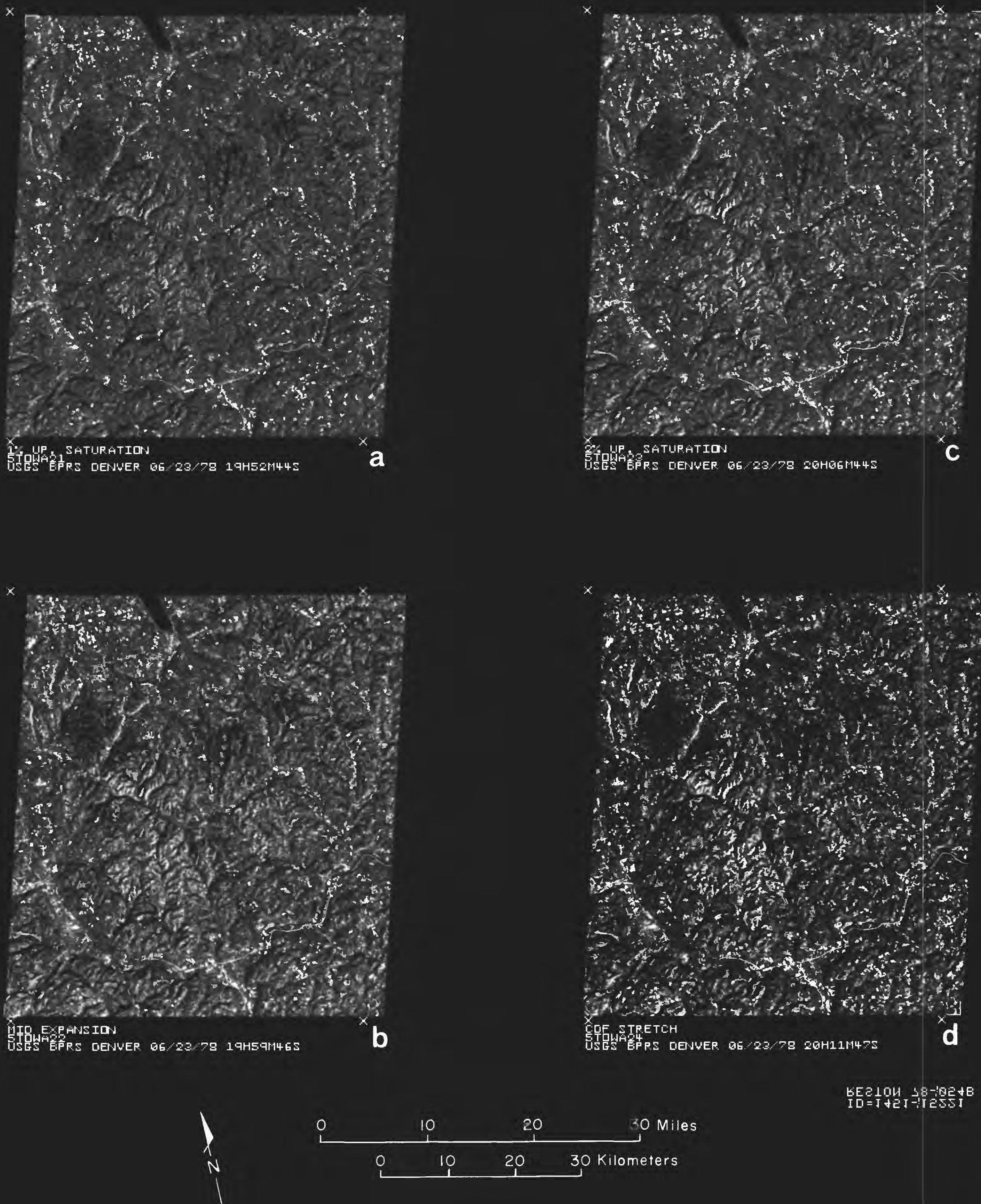
1% UP, SATURATION
STOWA21
USGS BPRS DENVER 06/23/78 19H52M44S
a
2% UP, SATURATION
STOWA23
USGS BPRS DENVER 06/23/78 20H06M44S
c
MID EXPANSION
STOWA22
USGS BPRS DENVER 06/23/78 19H59M46S
b
CDF STRETCH
STOWA24
USGS BPRS DENVER 06/23/78 20H11M47S
d
N
0
10
20
30 Miles
0
10
20
30 Kilometers

FIGURE 9

EDGE ENHANCEMENT

In image processing, the term edge enhancement denotes a variety of digital filtering techniques that are used to accentuate edges and sharpen boundaries within an image. Most edge enhancement techniques are, in effect, high-pass filters that emphasize spatial features of small frequency; whereas, spatial features of larger extent are subdued or filtered out.

One common method of edge enhancement involves taking a weighted average of the neighbors of a given pixel and adding this average to the pixel. In the edge enhancement programs of REMAPP, the eight neighbors surrounding a pixel are weighted by a Laplacian operator, which is represented by a 3x3 matrix of the following form (Reeves, 1975, p. 701):

$$\begin{matrix} 0 & -1 & 0 \\ -1 & +4 & -1 \\ 0 & -1 & 0 \end{matrix}$$

To control the severity of the edge enhancement, the weighted average is multiplied by a constant and then added to the the original DN value of the central pixel. In REMAPP, the useful range of the constant supplied by the user is from -1.0 to 1.0.

Edge enhancement was applied to the MSS band 5 image because the inherent low contrast of the image made topographic features appear indistinct. Three different constants for the edge enhancement were tested for the area surrounding Van Etten, New York (fig. 10). A constant of 0.5 (fig. 10b) seems to give the best edge enhancement. Note how roads and other cultural features are enhanced in the southwest corner of the image

Figure 10 - Comparison of three different edge enhancement constants applied to an MSS band 5 image, Landsat ID 1459-15221. The weighted average of a given DN value is multiplied by the constant and added to the original DN value; the constant controls the severity of edge enhancement applied to the image.

Fig.	Constant
10a	0
10b	0.50
10c	1.00
10d	1.25

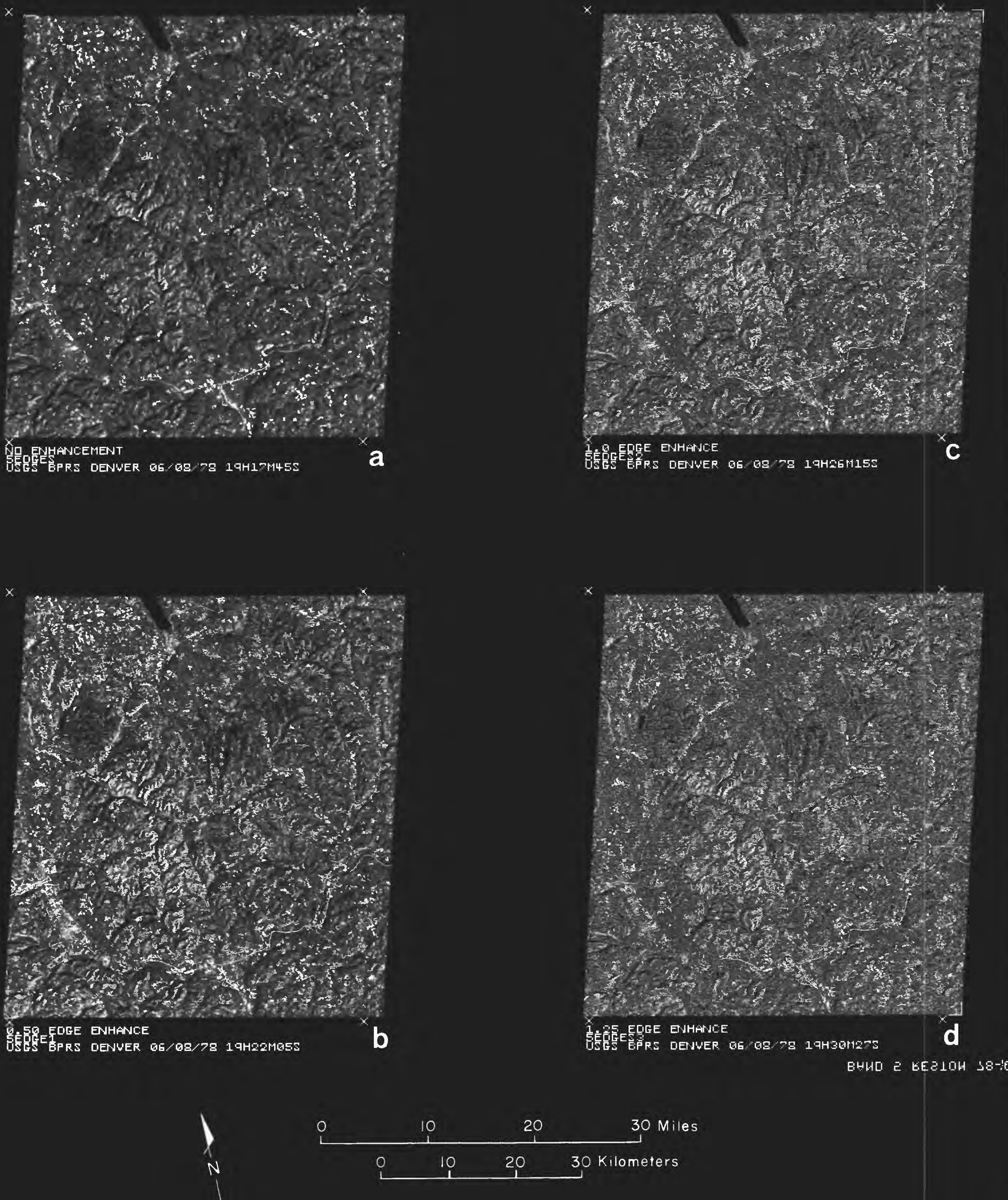
NO ENHANCEMENT
USGS BPRS DENVER 06/08/78 19H17M45S
a
1.0 EDGE ENHANCE
USGS BPRS DENVER 06/08/78 19H26M15S
c
0.50 EDGE ENHANCE
USGS BPRS DENVER 06/08/78 19H22M05S
b
1.25 EDGE ENHANCE
USGS BPRS DENVER 06/08/78 19H30M27S
d
N
0 10 20 30 Miles
0 10 20 30 Kilometers

FIGURE 10

near Elmira, New York. However, the edge enhancement also results in a salt and pepper appearance to the image that was not present in the original image and tends to hinder interpretation of topographic features. The effect of edge enhancement on image interpretation is a complex topic: certain edge enhancements can introduce artifacts into the image, such as ringing and directional fabrics, although symmetric digital filters, such as the one used in REMAPP, tend to reduce these effects (Gillespie, in press). Because the resolution of topographic features was not improved and because of the possible introduction of artifacts, edge enhancement for the New York scenes was not used.

Appended Images

The appended enhanced Landsat images for lineament analysis cover an area from Lake Ontario to Williamsport, Pennsylvania, at a scale of approximately 1:1,600,000 (figs. 11, 12, and 13). The original Landsat Computer Compatible Tape (CCT) splits this area into two scenes within orbit number 1459, but using REMAPP it was possible to splice together two scenes from the same orbit. The pixel size was reduced from 100 micrometers to 50 micrometers to accommodate the increase in the number of pixels. A simple linear contrast stretch was used for the final MSS band 7 image (fig. 11), whereas the more complex skewed three-point stretch, described above, was applied to the MSS band 5 image (fig. 12).

Examination of the appended images illustrates how digital image processing can affect the subsequent analysis of lineaments. On the MSS band 7 image (fig. 11), a northwest trending set of lineaments is prominent in the vicinity of Elmira, N.Y. (fig. 1). The southern arm of the "Y"

Figure 11 - Appended MSS band 7 image of south-central New York and north-central Pennsylvania, Landsat ID's 1459-15214 and 1459-15221. The contrast stretch combines the low end saturation of figure 4d with the high end saturation of figure 4b.

Input DN	Output DN
4	0
12	127
25	255

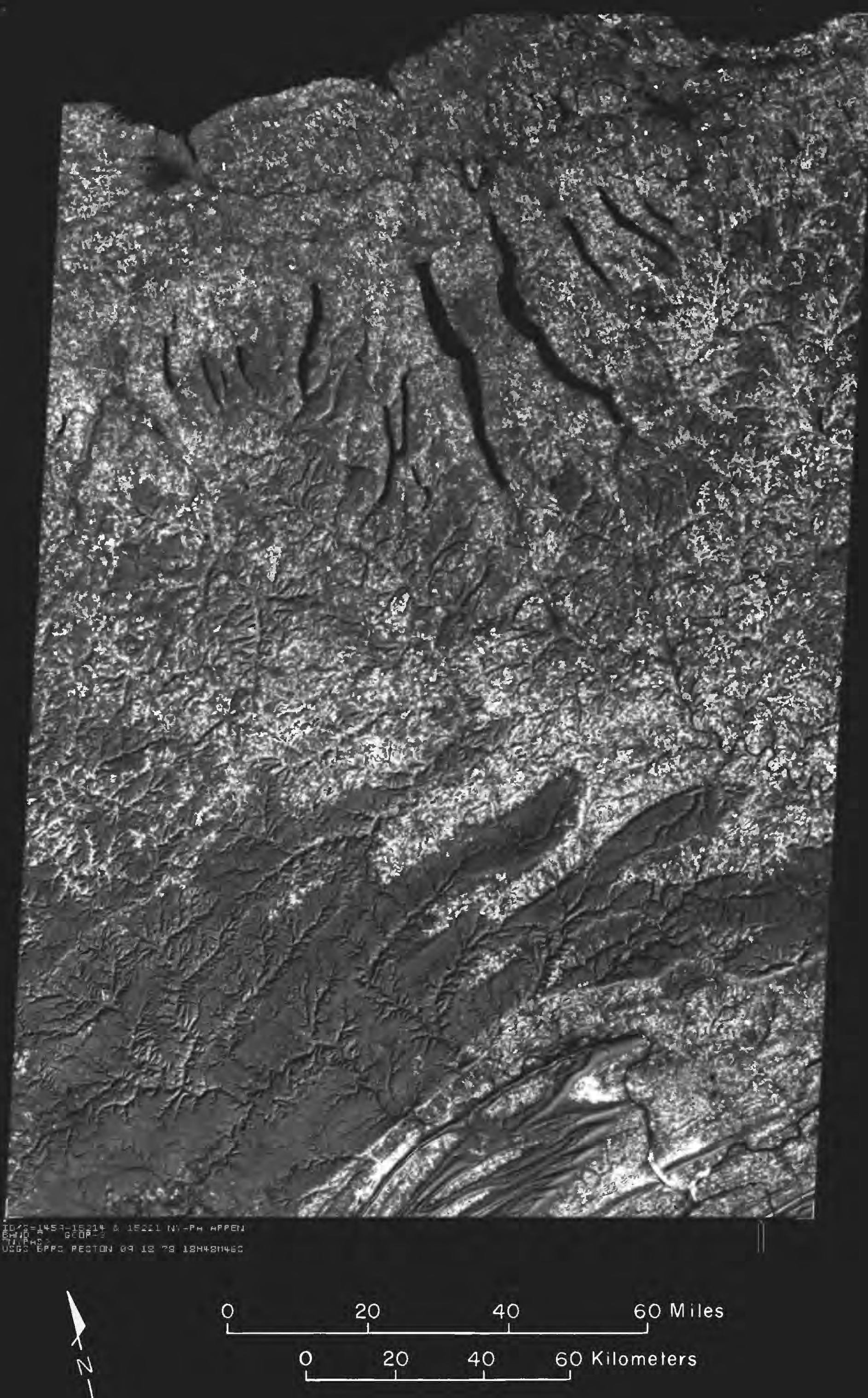

FIGURE 11

Figure 12 - Appended MSS band 5 image of south-central New York and north-central Pennsylvania utilizing the skewed three point linear stretch of figure 9b, Landsat ID's 1459-15214 and 1459-15221.

Input DN	Output DN
9	0
18	180
27	255

FIGURE 12

Figure 13 - Appended MSS band 5 image using standard three point stretch, Landsat ID's 1459-15214 and 1459-15221, for comparison with figure 12. This stretch is the same one used with figure 9a.

Input DN	Output DN
9	0
15	127
27	255

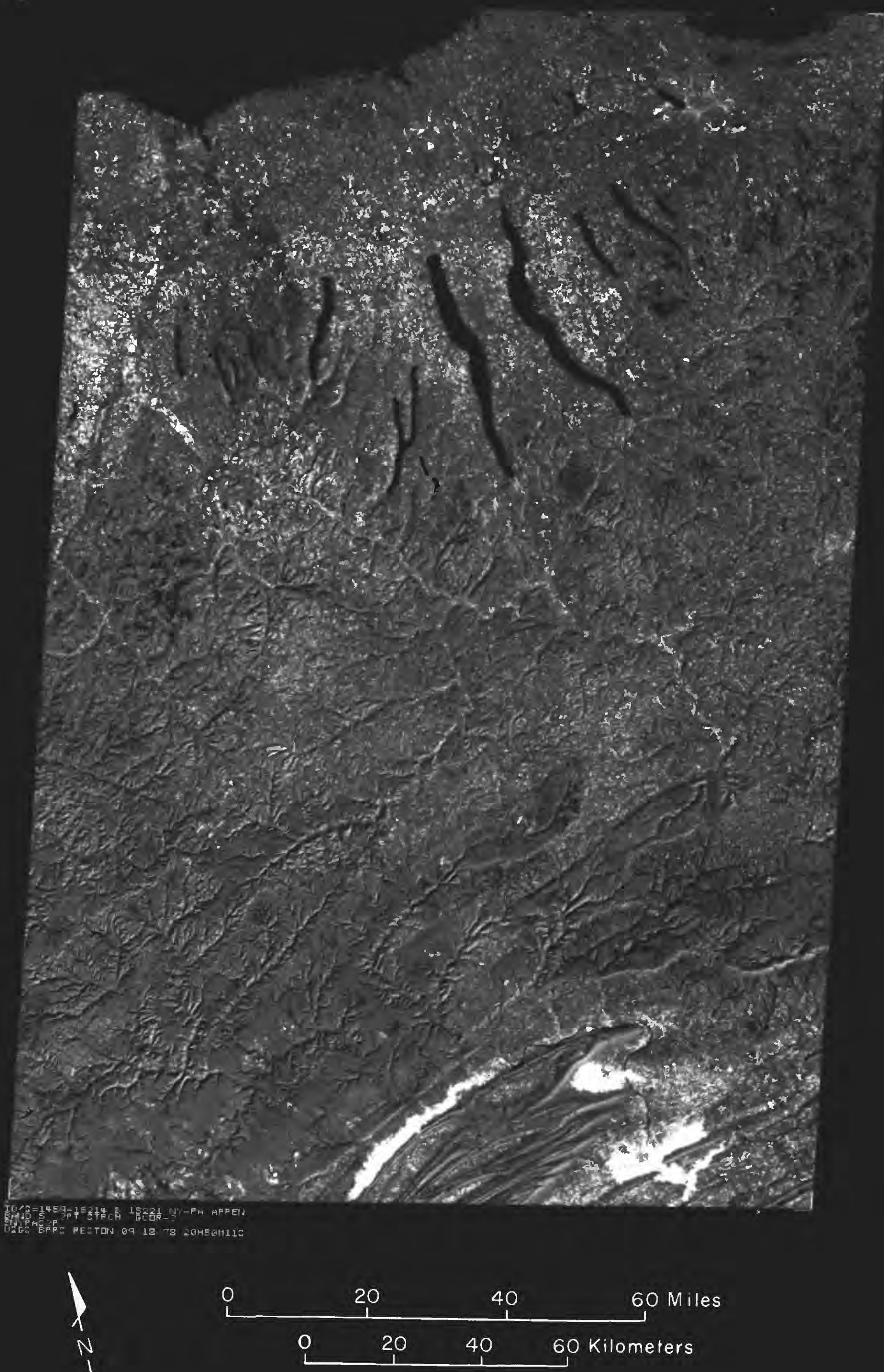

FIGURE 13

configuration of lineaments at Van Etten, N.Y. is part of the northwest trending set. In the MSS band 5 image (fig. 12), the "Y" configuration of lineaments at Van Etten appears relatively subdued. The most striking aspect of the MSS band 5 image in comparison to the MSS band 7 image is the appearance of an east - northeast trending set of lineaments south and east of Elmira. The eastern arm of the "Y" at Van Etten appears as part of a much longer feature with the same east - northeast orientation. Although parts of the ENE set are visible on the preliminary photographic prints (fig. 2) and on the other enhanced images (figs. 11 and 13), the full extent of the ENE set of lineaments is best observed on the MSS band 5 image with the skewed three-point stretch (fig. 12).

Stereoscopic Images

Stereoscopic viewing of Landsat images is advantageous for discerning topographic features, but is only possible in the area where two adjacent scenes overlap. Such sidelap amounts to approximately 30 percent for the Landsat scenes of New York; consequently, about one-third of the image on each side has stereo coverage, while the middle third of the image is without stereo coverage. Precession of the Landsat-1 orbit late in its life permitted acquiring additional stereo coverage of New York. The last pair of clear scenes of the New York area was acquired by Landsat-1 on 28 and 29 May 1977. By this time, the orbit had precessed approximately 22 miles (35 km) to the west from the 1973 orbit. Stereo coverage was extended to most of the remaining areas, except for a 15 mile (25 km) swath in the center of the image. Because these scenes were acquired near the end of Landsat-1's useful life, MSS band 4 is absent and striping is prominent in the other bands. Processing has not been undertaken yet for these Landsat-1 scenes.

Figure 14 is a stereo pair composed of the western half of the Scranton-Binghamton scene and the eastern half of the Elmira scene. Digital processing is usually needed to balance the images for optimal stereo viewing. Yet, note the differences between the two computer-enhanced scenes, although both images were acquired in October with nearly identical sun angles. Stereo relief is especially well-defined on the hillsides near Van Etten, N.Y. (fig. 1), and many topographic features are better defined stereoscopically than on either image alone. One side effect of stereo Landsat images is that the pixel grid itself has stereo relief; raised lines of pixels are visible parallel to the scan lines. Such lines are artifacts of a digital image, perhaps the result of six-line banding from the MSS, as no destriping was applied to the image. The net result is some loss of definition of features parallel to scanlines; however, the pattern is regular enough to separate out from most geologic features. The advantages of stereo are important enough to outweigh the disadvantages of such an artifact.

Figure 14 - Sidelapping MSS band 7 images used as a stereo pair. Scene to the west is 1459-15221 of 25 October 1973; scene to the east is 1080-15183 of 11 October 1972. Long east-west trending slightly arcuate line about one-third of the way down the image is a cloud or contrail.

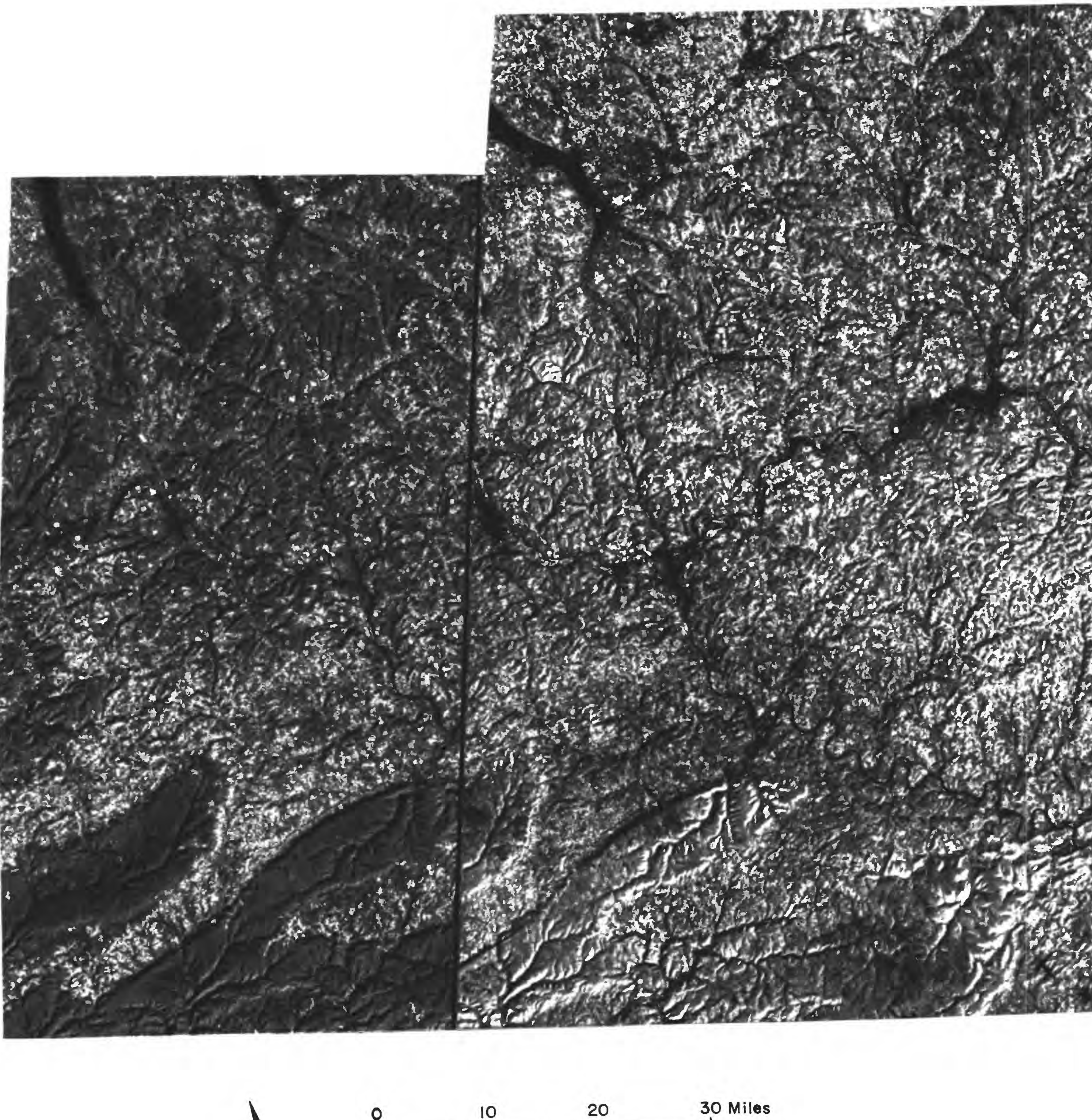

FIGURE 14

SUMMARY

From the preceding discussions, it is apparent that digital image processing can drastically change the appearance of a Landsat image from the unenhanced version. The role of digital image processing in geologic applications is to selectively enhance the image based on geologic considerations as much as possible. For the waste disposal programs, the goal of image processing is to enhance the topographic and tonal features that may constitute lineaments and other structural features of regional significance in the area of the Salina Basin in New York and Pennsylvania.

Selective contrast enhancement, based on analysis of the MSS histograms, is probably the most important factor affecting the appearance of the image. Three point linear stretches have been an effective contrast stretch for enhancing the heavily vegetated scenes of New York and Pennsylvania, particularly in the MSS band 5 images. A three-point stretch utilizes the two end points and a middle point of the Landsat DN frequency distribution and enables the operator to exercise more control over the image than is possible with the common two point linear stretch. However, effective use of a three-point stretch requires a sound understanding of the relationships between saturation, contrast, and placement of the middle point, as illustrated by the DNin vs. DNout graphs (fig. 5).

An edge enhancement was applied to the MSS band 5 image, but resulted in a spotted appearance to the image that tended to hinder the interpretation of topographic features. Moreover, because the effects of edge enhancement on image interpretation are not well understood and because of the possible introduction of artifacts, edge enhancement was not used for the New York images.

Use of sidelapping Landsat images as stereoscopic pairs aided recognition of topographic features. Digital processing is used to help balance the tone of the adjacent Landsat images for optimal stereo viewing. Some stereo artifacts from the pixel grid are apparent in stereo, but are sufficiently regular that they are not confused with geologic features. Stereo coverage for the New York area was increased by utilizing the precession of Landsat-1's orbit late in its life. The drawbacks to such late Landsat-1 images are the loss of MSS band 4 and pronounced striping in the other bands.

Digital image processing has been shown from the above discussions to improve the quality of images used for interpretation and to enable a more thorough analysis of lineaments to be compiled. A set of lineaments was recognized on the enhanced MSS band 5 image that became apparent only after extensive image processing had been completed. The constraints of image processing are the costs and logistical problems of producing a photographic product from an array of numbers. Because of the limitations of equipment, large quantities of images cannot be mass produced; rather, detailed analysis and experimentation of a few select scenes, using photographic prints to preview the scenes before processing, seems the most feasible approach.

REFERENCES CITED

Bredehoeft, J.D., England, A.W., Stewart, D.B., Trask, N.J., and Winograd, I.J., 1978, Geologic disposal of high level radioactive wastes -- Earth-science perspectives: U.S. Geol. Survey Circular 779, 15p.

Brunton, G.D., Laughon, R.B., and McClain, W.C., 1978, Screening specifications for bedded salt, Salina Basin, New York and Ohio: Office of Waste Isolation, Oak Ridge, Tennessee, Report Y/OWI/TM-54, 11p.

Cannich, M., and Gold, D.P., 1977, A study of the Tyrone-Mount Union lineament by remote sensing and field methods: ORSER Technical Report 12-77, Office of Remote Sensing of Earth Resources, Pennsylvania State University, University Park, Pa., 59p.

Colvocoresses, A.P., 1978, Landsat-3 return beam vidicon (RBV) imagery: U.S. Geological Survey Open-File Report 78-507, 3p.

Drahovzal, J.A., Nearthery, T.L., and Wielchowsky, C.C., 1974, Significance of selected lineaments in Alabama, in Third Earth Resources Technology Satellite-1 Symposium, Goddard Space Flight Center, Washington, D.C.: NASA Special Paper 351, Vol. 1, p. 897-918.

Gillespie, A.R., (in press), Directional fabrics introduced by digital filtering of images, in Podwsocki, M.H., ed., Proceedings of the 2nd International Conference on the New Basement Tectonics, July,1976, University of Deleware, Newark, Del.

Goetz, A.F.H., Billingsley, F.C., Gillespie, A.R., Abrams, M.J., Squires, R. L., Shoemaker, E. M., Lucchitta, I., and Elston, D. P., 1975, Application of ERTS images and image processing to regional geologic problems and geologic mapping in northern Arizona: Jet Propulsion

Lab. Tech. Rept. 32-1597, Pasadena, Ca. 188p.

Isachsen, Y.W., 1973, Spectral geologic content of ERTS-1 imagery over a variety of geological terranes in New York state, in Anson, A., ed., Symposium on Management and Utilization of Remote Sensing Data, Sioux Falls, S.D., Oct. 29-Nov. 1, 1973: American Society of Photogrammetry, p. 342-363.

National Aeronautics and Space Administration, 1971, Earth Resources Technology Satellite data user's handbook: NASA Goddard Space Flight Center, 218p.

Reeves, R.G., Anson, A., and Landen, D., 1975, Manual of Remote Sensing, The American Society of Photogrammetry, Falls Church, Va., 2144 p.

Rickard, L.V., 1969, Stratigraphy of the Upper Silurian Salina Group, New York, Pennsylvania, Ohio, Ontario: New York State Museum and Science Service, Map and Chart Series Number 12, 57p.

Rowan, L.C., Wetlaufer, P., Goetz, A.F.H., Billingsley, F.C., and Stewart, J.H., 1974, Discrimination of rock types and detection of hydrothermally altered areas in south-central Nevada by the use of computer-enhanced ERTS images: U.S. Geological Survey Professional Paper 883, 35p.

Sawatzky, D.L., and Townsend, T.E., 1976, Programmer's guide for REMAPP remote sensing array processing procedures: U.S. Dept. of Commerce, National Technical Information Service, PB-256 693, 38 p.

Taranik, J.V., 1978, Characteristics of the Landsat multispectral data system: U.S. Geol. Survey Open-file Report 78-187, 76 p.

Thomas, V.L., 1977, Generation and physical characteristics of the Landsat-1, -2, and -3, MSS computer compatible tapes: NASA Technical Memorandum 78018, 79 p.