INTERAGENCY REPORT NASA-181

GEOLOGIC STUDIES OF YELLOWSTONE NATIONAL PARK IMAGERY
USING AN ELECTRONIC IMAGE
ENHANCEMENT SYSTEM*

by

Harry W. Smedes**   copy 2

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GEOLOGICAL SURVEY

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ILLUSTRATIONS

GEOLOGIC STUDIES OF YELLOWSTONE NATIONAL PARK IMAGERY USING AN ELECTRONIC IMAGE ENHANCEMENT SYSTEM

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PURPOSE

This report describes the image enhancement system developed by the Philco-Ford Corporation; the kinds of enhancement attained; the results obtained from various kinds of remote-sensing imagery (mainly black and white multiband, color, color infrared, thermal infrared, and side-looking K-band radar) of parts of Yellowstone National Park; and possible additional fields of application of these techniques.

INTRODUCTION

Most images contain significant information which cannot be extracted by visual means only. Techniques or instruments that can amplify very small tone differences (color and density) which are on or even below the limit of visual recognition, or that can display arbitrarily selected density ranges and delete all other parts of an image, are important because they enable the interpreter to extract additional information.

In contrast, there may be more detail visible on the image than is desirable. Then it may be helpful to portray broad ranges in tone uniformly as a single tone or color. In this way, certain relationships previously camouflaged by tone mottling may be enhanced.

Some techniques for enhancing differences in tone are:

1) Photographic; by careful selection of types of film, neutral-density filters, printing paper, and developer, and control of exposure and (or) developing time.

2) Optical/electronic; by use of isodensitometers and isodensitracers, which measure density of film emulsion and can automatically "map" areas of equal image density.

•3) Electronic; by conversion of the film emulsion gray-scale into continuous or stepwise electronic signals that can be manipulated in various ways.

One electronic system, called IDECS (the acronym for Image Discrimination, Enhancement, Combination, and Sampling) was developed at the Center For Research, Inc., University of Kansas (Dalke, 1968). In this system, as many as four images are scanned simultaneously and the electronically processed signals are displayed on a color TV (television) screen. A somewhat different electronic technique is the subject of this report.

Early in 1968 the Space and Re-entry Division of Philco-Ford Corporation began to develop a video enhancement system (fig. 1) which portrays differences in film emulsion gray-scale as differences in color. Their present system comprises an electronic image processor capable of handling two separate multiband or color separation transparencies, a color video display, and a light table and master power panel. This system provides a means of electronically scanning either 1 or 2 transparencies and displaying various combinations of the video and digitized video signals on a 1,000-line TV screen. The information is displayed in color by mixing various amounts of two components of the video signals and viewing the screen through a transparent color wheel--a process that was used in some of the early color TV sets.

The following brief description of the enhancement system is included so that the reader will more fully understand what the resulting image represents. A more detailed description is contained in a report by the Philco-Ford Corporation.[1]/ I am grateful for the

Figure 1.--Console for electronic image enhancement system.
Right, electronic image processor; center, color video
display; left, light table and master power panel.

DESCRIPTION OF PROCESSING SYSTEM

In simplified form this system works as follows: transparencies consisting of pairs of color-separation negatives, multiband photographs[2/],

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[2/] Color-separation negatives are made from color prints or transparencies by successively photographing the color image with black and white film using different color filters. For example, only the red component of the color image will be shown on the black and white film exposed using a red filter. The red, green, and blue color-separation negatives collectively contain all the color information contained in the original color image.

Multiband photograph transparencies were obtained by photographing the natural terrain with an aerial 9-lens camera system--each lens filtered to receive a different restricted part of the spectrum from violet to the near infrared. These 9 simultaneously obtained filtered images are analogous to 9 different color-separation negatives.

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or single black and white images can be used. As shown in the diagram (fig. 2) the system utilizes a high-intensity flying-spot scanner (S) for generating electronic images analogous to those recorded on a pair of the transparencies (T). A partially silvered beamsplitter and a mirror provide simultaneous illumination for these slides, which are images as much as 3 x 4 inches in size made in each of two preselected spectral bands. The flying spot scans rapidly across the tube face and is focused by lenses (L) onto the slide transparencies. The amount of light from the scanner which passes through the slides is proportional to the density of the film emulsion. Photomultiplier tubes located behind each slide measure the amount of transmitted light. The output signals from the tubes pass through identical amplification and processing channels to mixers (shaded). The resultant video display signals are processed in an amplifier/multiplexer (AM) for synchronous mixing and display on the black-and-white TV monitor. The observer views this monitor through a rapidly rotating red and green color wheel. The red and green video signals are synchronized by a TV synch-generator with a 60-cycles per second power source serving as a common timing reference throughout.

The current from each photomultiplier tube is apportioned into two separate circuits by means of mixers. Although only in the form of electrical current, these circuits are labeled "Red video" and "Green video," for they will be seen on the screen as red and green.

Both circuits called "red" are combined and both called "green" are combined. An automatic switch alternately flashes one circuit and
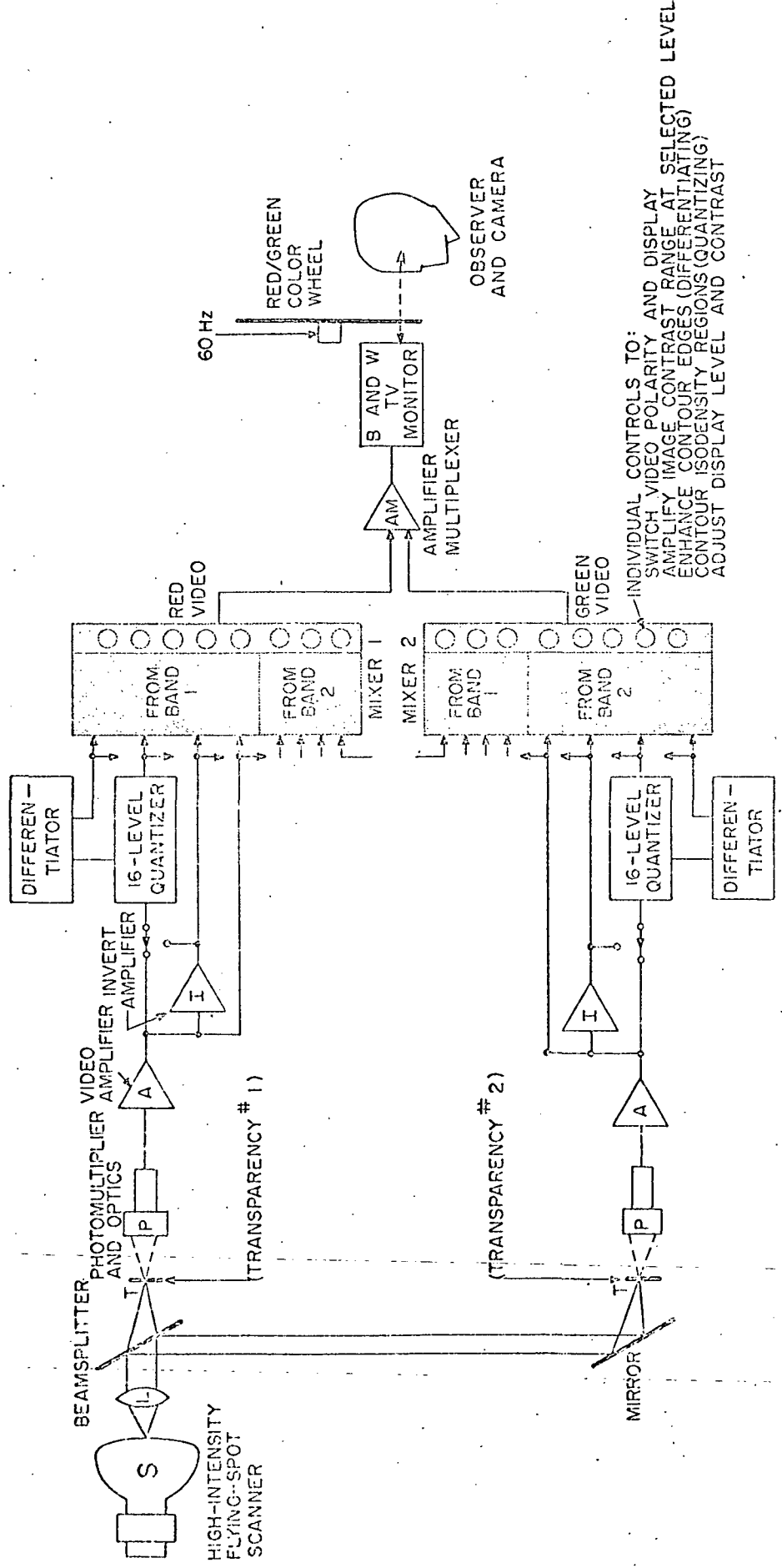
Figure 2.--Generalized diagram of electronic image enhancement system. Modified from data furnished by Philco-Ford Corporation.

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then the other onto a TV screen, each at 30 cycles per second. The
switch is synchronized with a motor-driven color wheel with alternating
red and green filters, located in front of the TV monitor. When the
circuit labeled "Red video" is on the TV screen the red filter is in
front of the screen. When the circuit labeled "Green video" is on,
the green filter has moved into position in front of the screen. Thus,
red and green images are alternately displayed, but the speed of
alternation is faster than flicker speed; the resulting sensation is
one of continuous mixed color in various hues of red, orange, yellow,
and green.

ENHANCEMENT FUNCTIONS
Mixing

By means of the two mixers (shaded areas on fig. 2), the proportions
of red and green from each transparency are controlled and can be
changed from entirely red, through all proportions, to entirely green.
If only one transparency is used, and the current in the two circuits
from it is about equal, the image on the TV monitor is various shades
of yellowish orange. Applications of mixing are given below in the
section on density matching (p. 12).

Color mixers can be adjusted so that all the current from
transparency 1 goes to the red circuit and all from transparency 2 goes
to the green circuit, for example. In that case, we have done away
with the proportioning, and this would be closely analogous to a two-
projector optical system of studying multiband imagery. Important
differences are that, with the electronic devices, we can arbitrarily
reject all densities that fall outside selected thresholds, perform a
wider range of positive and negative displaying, and do quantizing and
differentiating.

Change of polarity

In addition to a simple video display, one or both of the circuits
(red and green) from each of the two channels can be displayed in normal
or reverse polarity so that at the flick of a switch we can change from
a positive to a negative image on the screen, or positive red and
negative green, or the positive image of transparency 1 registered with
the negative image of transparency 2. Examples are positive-negative
masking which are described in the section on two-band processing
(p. 11).

Quantizers for density slicing

Provision is made for breaking or slicing the continuous gray-scale
curve of the image emulsion density into 16 discrete steps, or fewer.
Each of the inputs is associated with a 16-level quantizer. The input

waveform, hence the film density, is broken or sliced into 16 contiguous levels, each of which is assigned, electronically, a specific color proportion of red and green. (This is achieved through a color-selection matrix which consists of a set of potentiometers.) When operating in this mode, specific density levels in the transparency correspond to specific colors on the TV screen. This is illustrated in figure 3. The smooth line is a standard photographic density curve which shows film emulsion density versus log of the exposure. The steps illustrate how the quantizer treats the continuous curve of density as a discontinuous step function of 16 discrete levels.

The 16 levels can be spread evenly over the entire density curve (upper part of fig. 3) or they can be shifted up or down the curve so that only the densest or least dense parts of the image are quantized (fig. 4). Straight shifting of this ramp would result in fewer slicing levels--for example, 4 at A and 3 at B (fig. 4). However, the spacing of the levels can also be adjusted, being made broader or narrower. For example, all 16 levels may be restricted to the toe (fig. 4C), to the straight part (fig. 4E), or to the shoulder (fig. 4D) of the curve; in the third instance all other density levels are deleted. In this way, especially small differences in tone can be enhanced. Note that the spacing of the slicing levels can be adjusted to fit the nonlinear parts of the density curve (fig. 4D).

The 16-level quantizer in each channel provides the electronic equivalent of photographic isodensity contouring over a selected range of film density or scene brightness. Differentiators are supplied at the outputs of the quantizer for optional provision of signals to enhance the edge of the isodensity contours by triggering at each change in discrete level. The film-density or scene-brightness bands defined by each of the 16 levels are contiguous. The 16 output signals feed a resistor-summing network that produces a stepwise-constant video waveform which is then sent to the two mixers. The end result is a signal-processing circuit having a nonlinear transfer function. The desired transfer function can be tailored for a specific task by changing the resistors in the summing network. In addition, by resistor selection, each of the 16 digitized brightness levels may be assigned individually to either of the display colors.

Processing

The present system is capable of processing 1 or 2 images. The Philco-Ford Corporation plans to expand the system to accommodate four images. Two or more images would be used for processing multiband or
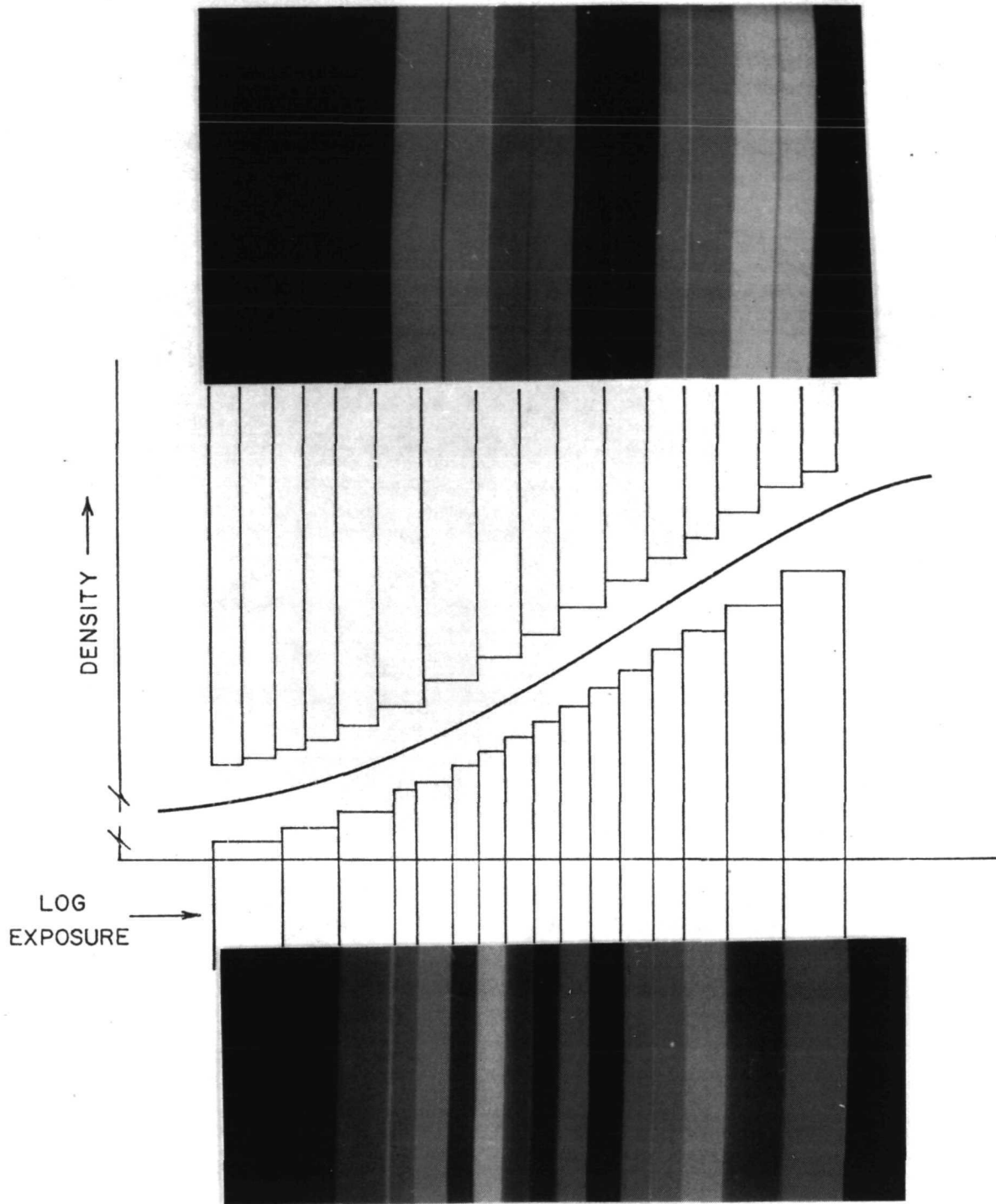
Figure 3.--Diagram illustrating 16-level quantizing of image density curve. Color photographs were taken by means of an internally generated ramp waveform which determines position, width, and color of the density levels or slices. Upper photograph illustrates subequal spacing of slices throughout the density range. Lower photograph illustrates how the spacing can be made nonlinear, to fit nonlinear parts of the density curve.
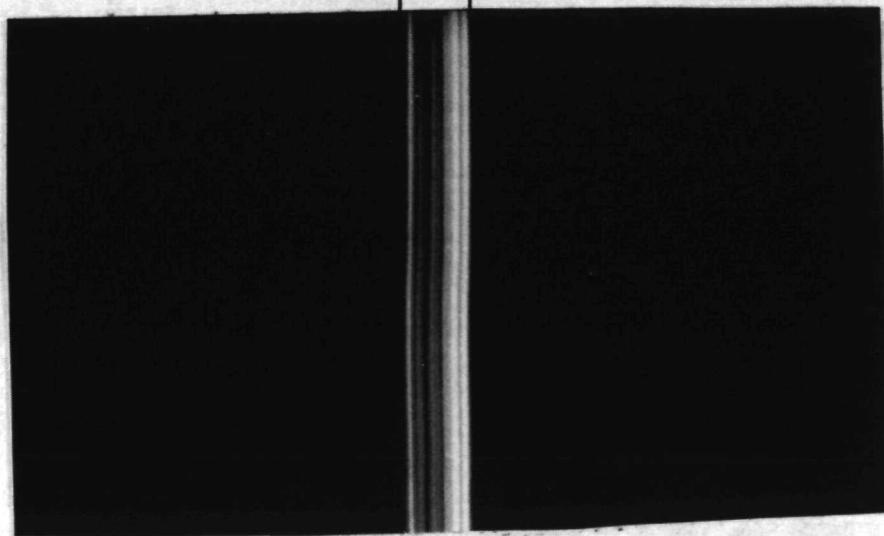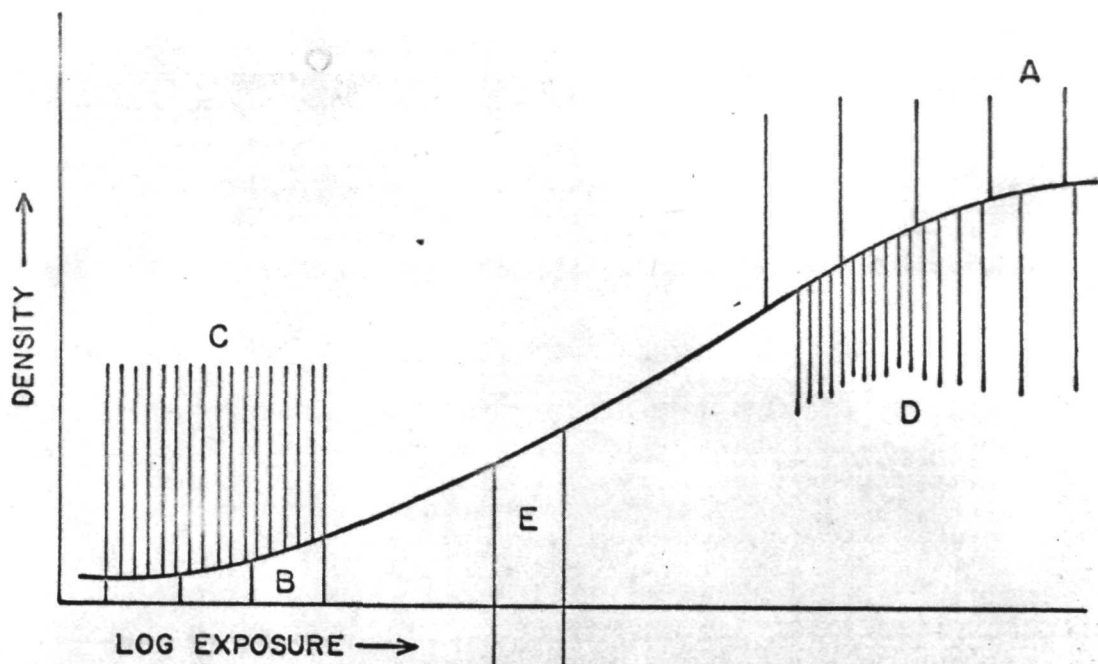
Figure 4.--Diagram illustrating different positions and widths and density
slices. Color photograph illustrates all 16 levels equal in width and
restricted to the central part of the density curve. Letters are
referred to in the text.

color-separation transparencies. Processing of one image only is principally for one-band rather than multiband imagery (that is, where spectral filtering cannot or has not been done, such as X-ray, radar, and thermal infrared images, and conventional black and white aerial photographs).

Examples of the following kinds of processing of one-band and two-band (multiband) images are illustrated in figures 5-13.

ONE-BAND PROCESSING
Density slicing

The 16-level quantizer permits displaying zones of equal density range. By selection of proper quantizing levels on single black and white photographic images, all or most areas of bare bedrock and talus, of vegetated areas, or of water can be delineated because each of these categories of material tends to have different and limited ranges of reflectance.

The contacts between adjacent density ranges constitute isodensity contours. Therefore, thermal IR images can be transformed into thermal contour displays (fig. 5 and 6). With ground information or other thermal control, these images become quantitative thermal maps. Enhanced single images are shown in figure 13A, where surficial deposits, timber, and grassland are contrasted with hot spring deposits and landslides. Similar processing of other images can yield quantitative contour data on depths of bodies of water.

Enhancing different parts of the density curve

By shifting the position and width of the 16-level quantizer, various density contrasts can be emphasized. Subtle differences in the least dense regions of the scene can be enhanced if the ramp is shifted toward the toe of the density curve; denser regions can be enhanced by shifting to the shoulder of the curve (C and A, respectively in fig. 4).

A radar image (fig. 7) was processed in this way, to enhance linear features of different trends.

TWO-BAND PROCESSING

By electronically combining the signals from two (in the future, four) images, additional kinds of processing can be performed, as shown in figures 9-13.

The images used for the two-band experiments were color-separation negatives made from color and color infrared film, and multiband images

from the ITEK 9-lens camera. The color-separation negatives were made
by Philco-Ford Corporation. The transmission curves[3] for the 9-lens

[3] Data from: Introduction to NASA 926 and NASA 927, Remote Sensor
Aircraft as applied to the earth's resources survey program. Flight
Research Branch, Aircraft Operations Office, National Aeronautics and
Space Administration, March 19, 1966.

imagery are shown in figure 8.

The following enhancement techniques were tried using the
Yellowstone National Park imagery: density slicing, enhancing different
parts of the density curve, masking, redundancy test, edge enhancement,
density matching, and generalizing of tones.

Density slicing

The 16-level quantizers, described above, can be adjusted so that
the relative widths of the 16 levels are different for one channel than
for another. This permits a wider range of enhancements than with one-
band processing, and permits additive as well as subtractive
manipulation. The effects of wide versus narrow spacing, and position
of the quantizer ramp can be examined rapidly by switching on first one
quantizer and then the other and by exchanging positions of the two
images.

Enhancing different parts of the density curve

The quantizer for one image can be shifted to enhance one part
of the curve while the quantizer for the other image can be used to
enhance some other part of the curve. Further range is afforded by
switching polarity.

Masking

One function of changing polarity is to accomplish positive-
negative masking. In this way, all materials on the ground that have
high reflectance in wavelength band (frame) 2 and low reflectance in
band 7, for example, can be enhanced by combining the positive of
transparency 2 with the negative of transparency 7. Areas of high
reflectance in band 2 but also high or intermediate in 7 would not be
enhanced.

The detection of bodies of gypsum is an example of a possible
application of this masking technique. Weathered gypsum at the earth's
surface has high reflectance in the ultraviolet and very-low emittance

in the thermal infrared (Wolfe, 1969). By combining the ultraviolet positive (=bright) and the thermal infrared negative (=bright), areas underlain by gypsum should be reinforced and markedly enhanced on the resulting image.

Redundancy test

Another function of masking is to test for redundancy of data. We know that we don't need all 9 images of the 9-lens multiband camera for any one experiment; in fact, 4 probably is the maximum number. To test whether, or how much, new information is contained in image 1 compared to image 2, etc., we can balance the red-green mix on each so that we have roughly a neutral--that is, yellowish orange--image of each, and then reverse the polarity of one of the images. This gives us a superimposed positive of one, and negative of the other. If the screen is featureless, there is complete redundancy of data. When details show up, it indicates that one transparency contains information that the other does not. An example is shown in figure 9. The high contrast obtained from widely separated spectral bands by this positive/negative masking technique (fig. 9B) also is a means of edge enhancement.

Edge enhancement

If we now use the same setup as just described for the redundancy check, and deliberately misaline the two transparencies, the result is high contrast or edge enhancement along the contacts between areas of different density or brightness (fig. 10D). In fact, with any complementary pair of transparencies, if one is positive and the other is negative, we will get an edge enhancement even without misalinement (fig. 10C).

Advantages of this process over other techniques for edge enhancement include the visual display (versus computer printout, for example), several color zones shown simultaneously, and the preservation of geometric image fidelity.

Density matching

One of the reasons for proportioning the signals for each of the transparencies to both the red and green video circuits is as follows: If we adjust the color in such a way that the same density in each of the 2 transparencies is, for example, red, then when these 2 signals are combined they reenforce each other so that we have a still brighter red on the video screen. In this way we know that the same density value (that is reflectance) occurs in that given spot on the scene for both the spectral bands and we know that wherever else red appears that same density occurs on both transparencies. Other colors will indicate different densities. In a sense this is a redundancy check because it shows us that wherever one particular color (in this case red) occurs the same information is contained in both transparencies.

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Generalizing of tones

As noted above it is desirable at times to be able to subdue the amount of detail and range in image density in order to see or portray more conspicuously the distribution of material of a certain broad category. By correctly positioning the quantizer ramp, with increments spread to maximum width, this generalizing of tones can often be accomplished. An example is given in figure 11.

RESULTS--ANNOTATED IMAGES

The following pages contain selected examples of images used and the enhanced product. Expanded captions provide the necessary descriptions.

All the enhanced images were produced by photographing the black and white TV monitor through the red and green color wheel using 35 mm color film. The camera was placed in the position normally taken by the observer (fig. 2).
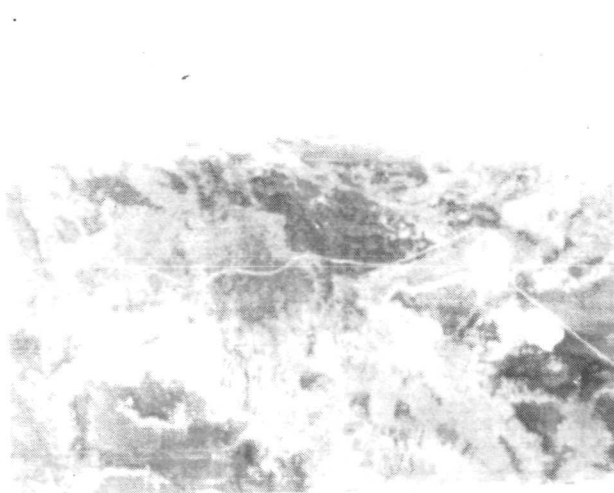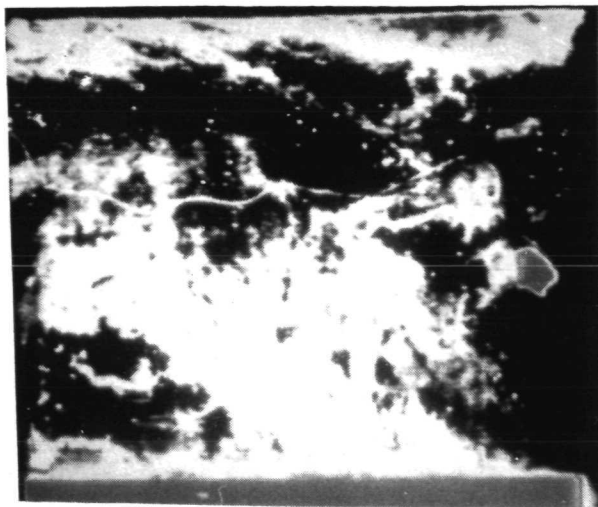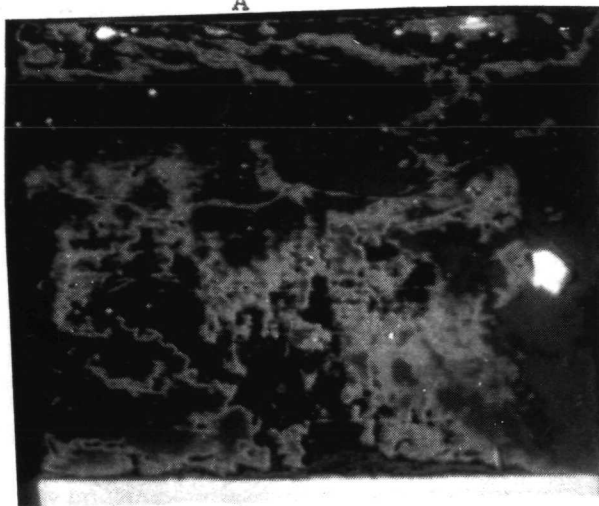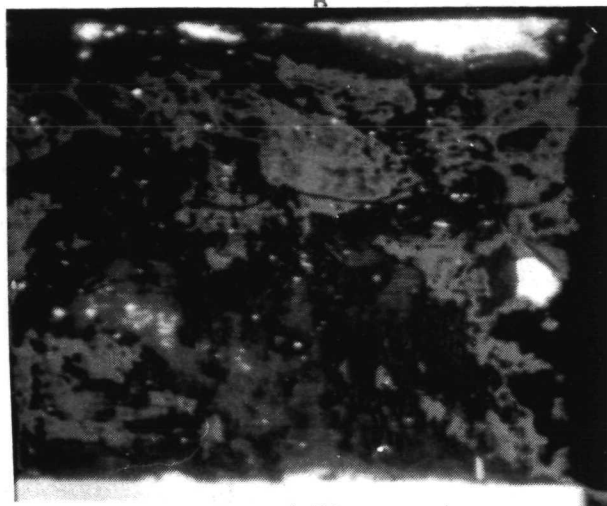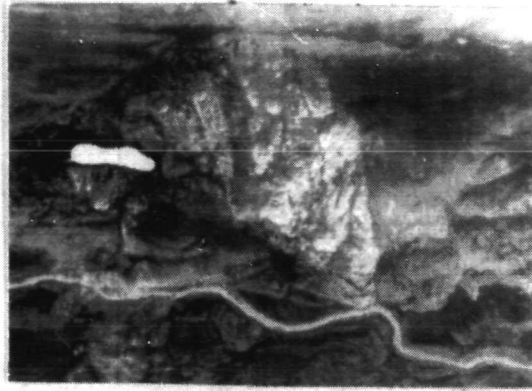
Figure 5.--Thermal infrared and enhanced images of area near Floating Island
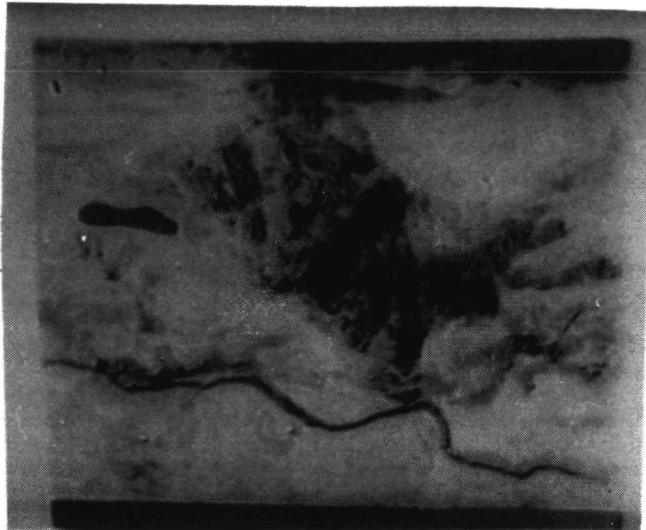Lake, north-central Yellowstone National Park.
The 8-12 μm thermal infrared image (A), was taken at 2 a.m., mid-September
1967. The warmest object in the scene is the lake, which appears as a light
tone contrasting strongly with all other tones on the image. A blacktop road,
bedrock and talus of volcanic rock, and forested areas all appear as medium
gray tones, and meadows appear as dark tones (coldest objects in the scene).
The first color display (B) presents the lake as orange, all intermediate
temperatures as green, and all cold areas as black. This is an example of
clarifying categories by deleting tone mottling that conceals broader
relations of categories (or generalization of tones).
In another display of the same scene (C), the objects of intermediate
temperature (tone) are subdivided into 4 thermal slices, and the cold materials
into 2, all distinctly bounded in contrast to the hazy ill-defined boundaries
shown in the original image (A).
In the last display (D), a great variety of detail and color tones are shown
subdividing the scene into six color slices as in C, except that the greens
and reds are reversed, and the darker scene elements (shown as green) show
far greater detail than in C, although there is little or no geologic value
in obtaining this detail.

A

B

Figure 6.--Thermal infrared and enhanced images of an area west of the
   Buffalo Plateau, north-central Yellowstone National Park.
   The 8-12 μ m thermal infrared image (A) was taken at 2 a.m. mid-
   September 1967. The warmest object in the scene is a lake (left
   edge). The Yellowstone River (lower edge) and a large mass of
   granitic gneiss (left-central area) shown as intermediate temperature.
   Grasslands are darker gray, and forested areas black.
   In the processed image (B) the lake, river, and all bedrock exposures
   (granitic gneiss) have been enhanced to show as orange, in contrast
   to soil meadows, and forest, which show as green. This image
   constitutes a "map" showing distribution of bedrock outcrops.
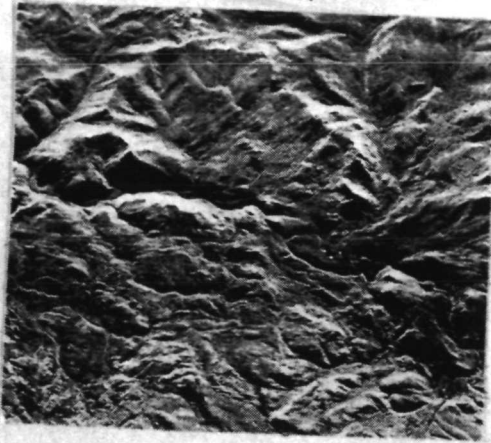
A
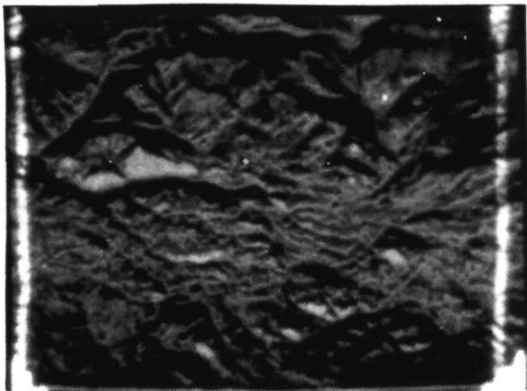
B
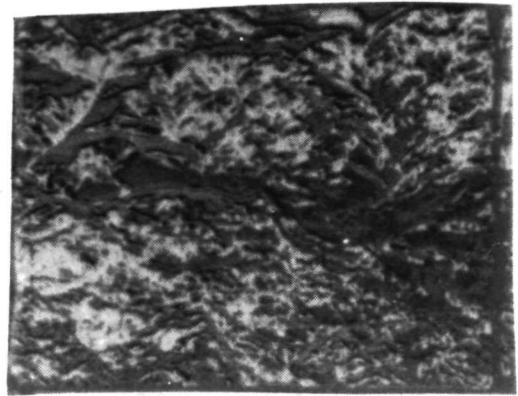
C

Figure 7.--Side-looking K-band radar image and enhanced images of an area
in north-central Yellowstone National Park. Look direction is to the
south (north is toward top of page).
The radar image (A) covers an area along the Yellowstone River from the
mouth of Crevice Creek eastward to the mouth of Lava Creek. Lineaments
of northwest and northeast trend, respectively, are enhanced in images
B and C. In B, the light-colored lineaments are enhanced; in C, the
dark lineaments are enhanced. Also, in C, and dark areas of radar
shadow and the extensive surfaces of low relief in the central and
east-central parts are shown as red in contrast to the areas of high
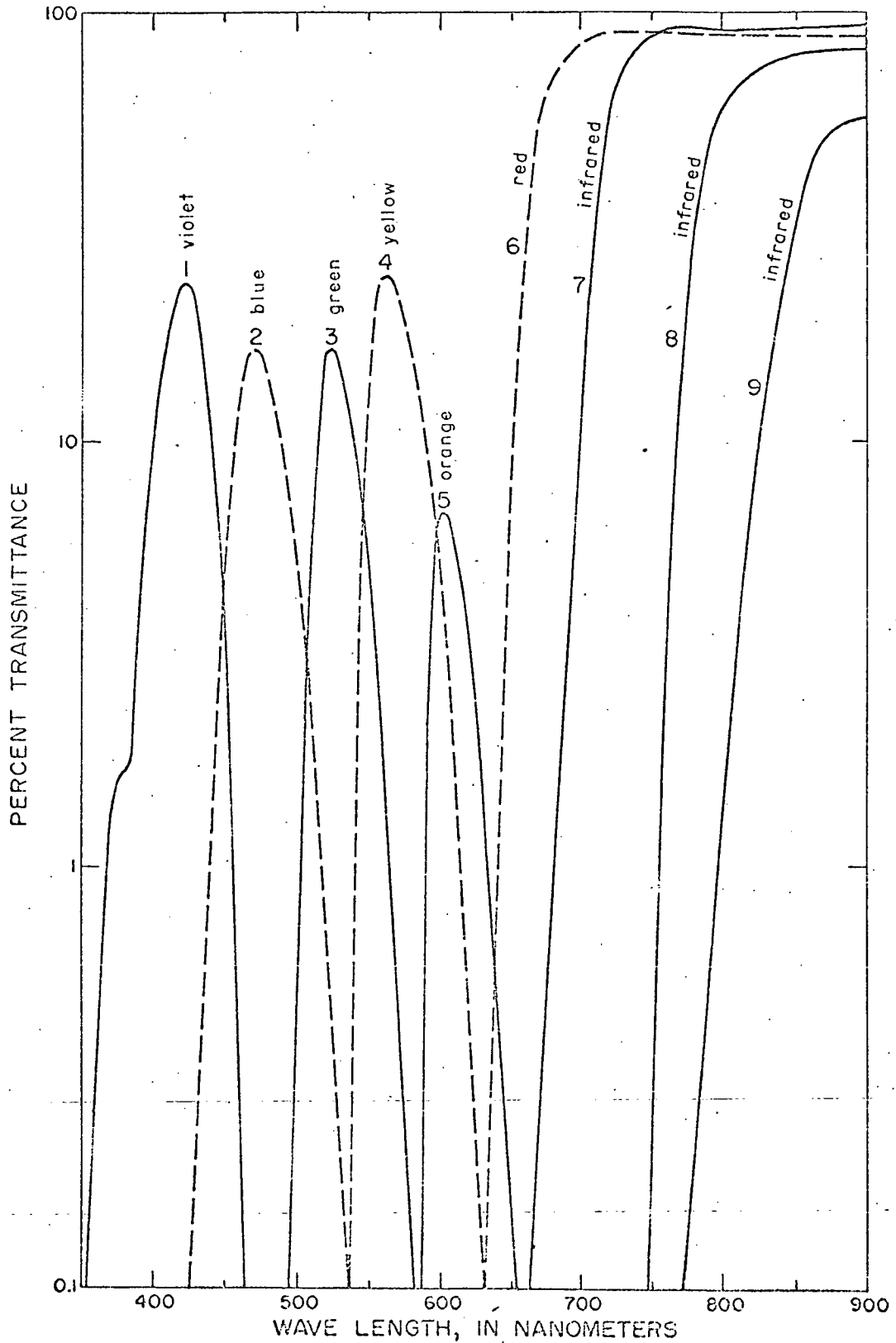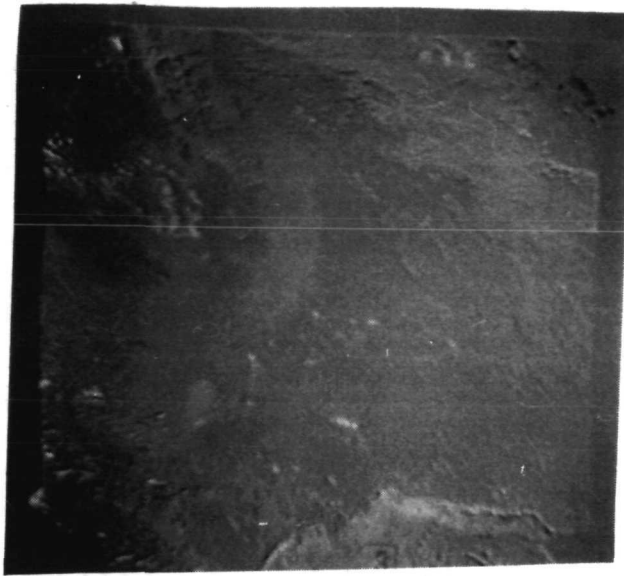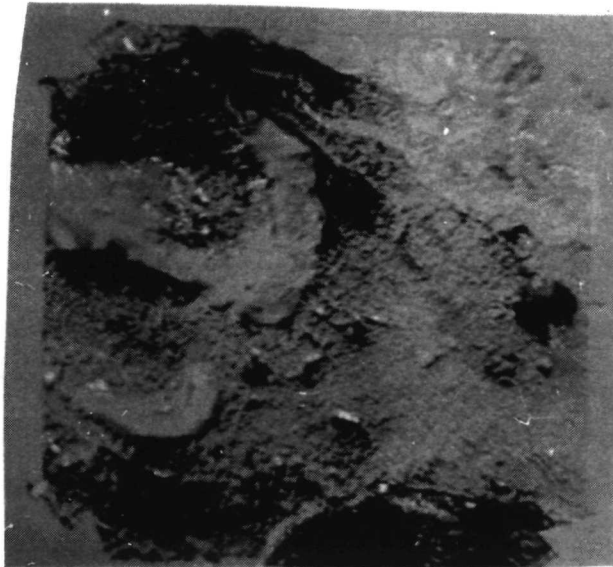relief, shown as green.

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Figure 8.--Nominal transmission curves for multiband filters used with ITEK 9-lens camera. Numbers identify frames described in text. Data from NASA.
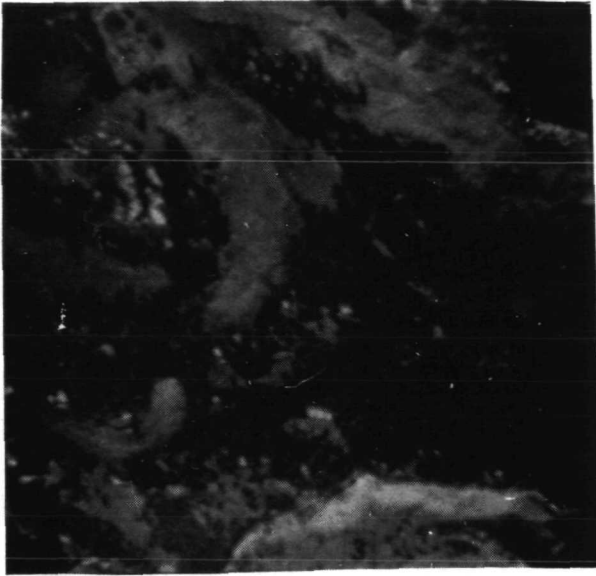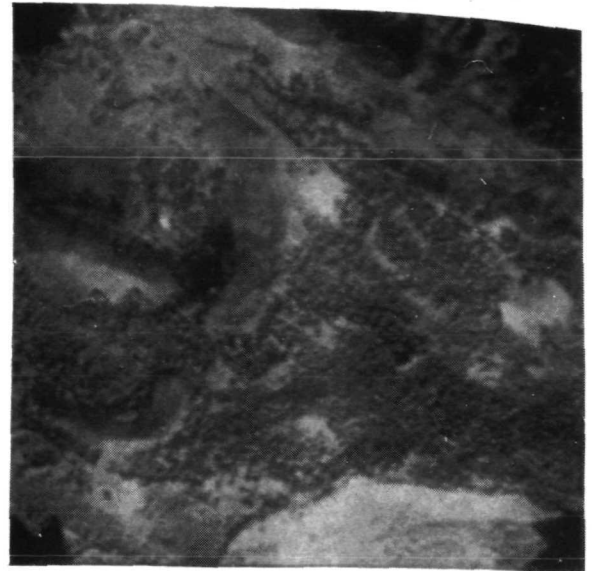
A

B

Figure 9.--Example of redundancy test. Multiband photograph images of an area in the southern part of the Gallatin Range. Area same as shown in figures 10 and 12.
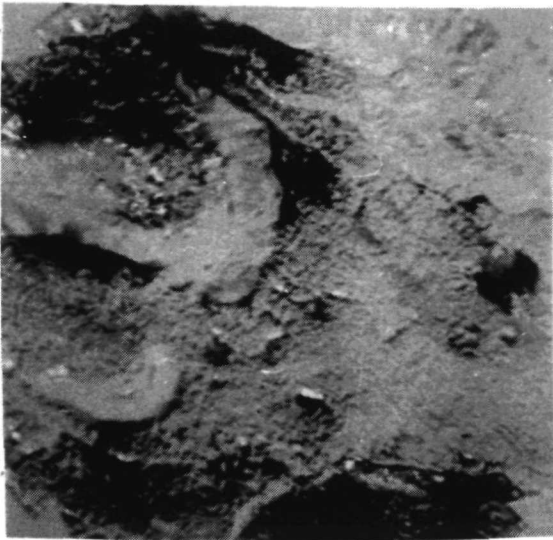A. Positive of frame 3 superimposed on negative of frame 4. High degree of redundancy is indicated by low contrast.
B. Positive of frame 3 superimposed on negative of frame 9. Low degree of redundancy is shown by high contrast.
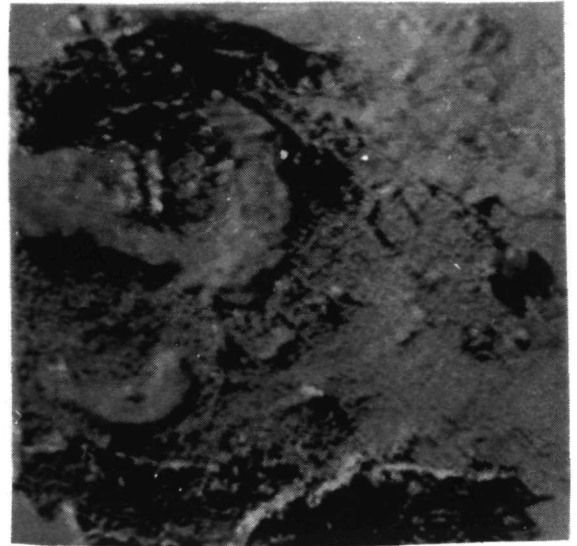
18

A

B

C

D.

Figure 10.--Examples of edge enhancement by positive/negative masking. Photographic images from multiband 9-lens camera of an area in the southern part of the Gallatin Range; area same as shown in figures 9 and 12.

A. Video image of frame 3.

B. Video image of frame 9.

C. Positive of frame 3 superimposed on negative of frame 9, as in redundancy test (fig. 9B).

D. Same as C, but with images slightly misalined to enhance edges.

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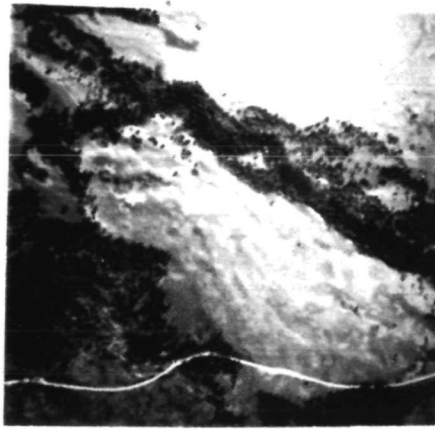
A
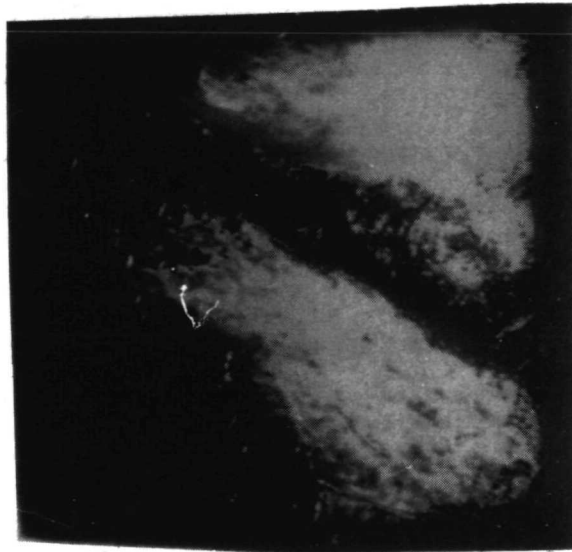
B

Figure 11.--Print and enhanced image from color-separation negative of
area west of Floating Island Lake.
   A. Print from red color-separation negative made from color film,
       showing meadows on kame terrace deposits surrounded by forest.
       Highway from Mammoth to Tower Junction shown near bottom edge.
       Though both large meadows are on kame terraces--note the great
       difference in appearance--one is mottled and the other is rather
       uniform.
   B. Enhanced image from the red and green color-separation negatives
       showing generalizing of tone such that both meadows appear
       uniform (green) in contrast to the forest (red).
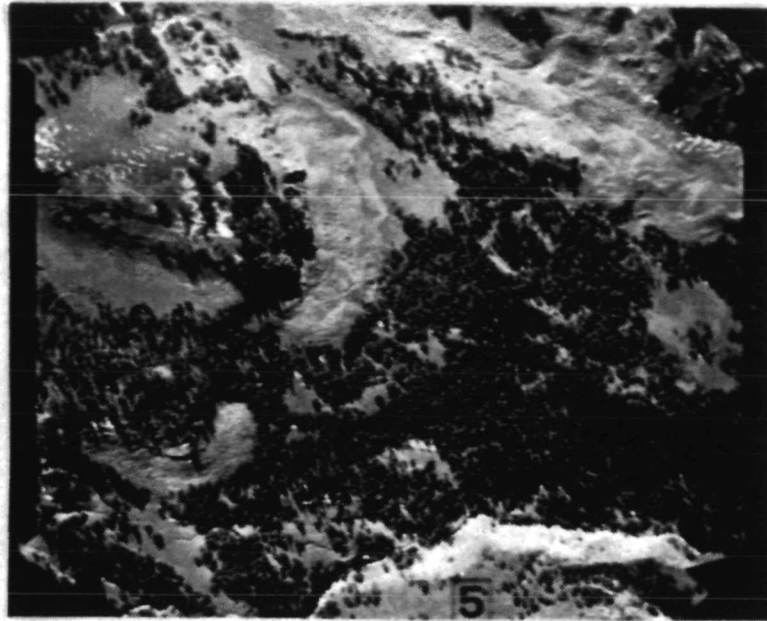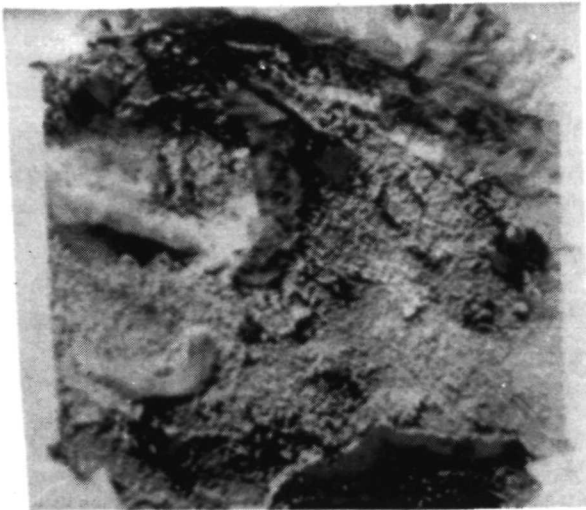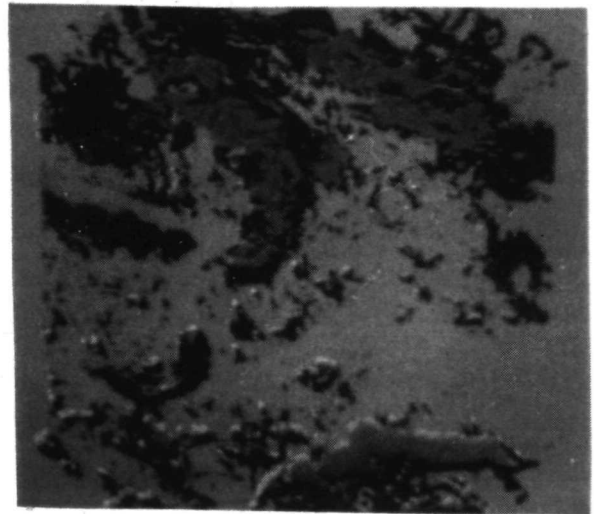
Figure 12.--Photograph and enhanced images of an area in the southern
part of Gallatin Range. Area same as shown in figures 9 and 10.
A. Photograph (frame 5) from multiband 9-lens camera.
B. Enhanced single image (frame 6): red, outcrop, sliderock,
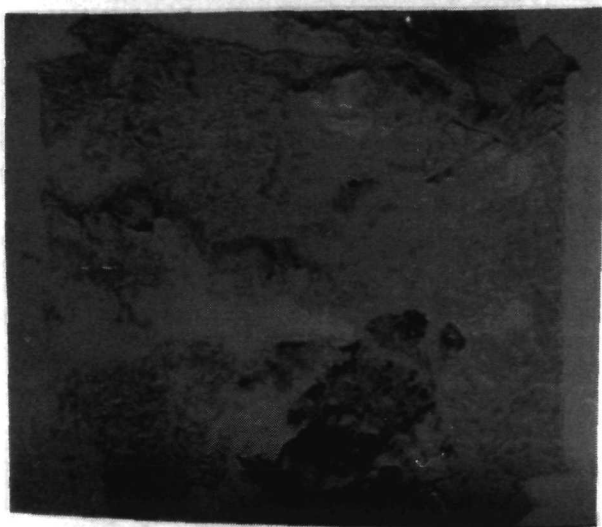and coarse moraine; green, finer surficial deposits, timber,
and grassland.
C. Enhanced combined images (frames 2 and 7): red, outcrop,
coarse sliderock, and moraine; green, finer surficial
deposits, timber, and grassland.

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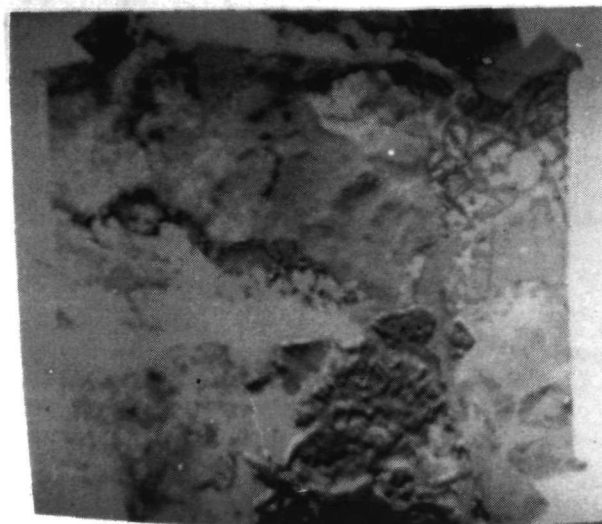
Figure 13.--Photograph and enhanced images of Mammoth area.
  A. Photograph (frame 5) from multiband 9-lens camera.
  B. Enhanced single image (frame 6): red and orange, hot spring
       deposits (bottom), landslides (top), and some cultural features;
       green, other surficial deposits, timber, and grassland.
  C. Enhanced images (frames 2 and 6): red, hot spring deposits;
       green, most surficial deposits and all vegetation.

CONCLUSIONS AND RECOMMENDATIONS

The described limited tests indicate that the Philco-Ford Corporation electronic image enhancement system can be very useful in geologic studies. In many places bare rock can be distinctly separated from soil, grass, or forested areas; and, although different kinds of rock were not separated in these experiments, such separation is within the capability of the system.

In terms of reflectance, bare rock in place (bedrock) cannot always be distinguished on the basis of reflectance from bare rock (debris) that has moved as talus, sliderock, or as large boulders in surficial debris, but in surface forms they each generally are distinctive. Similarly, in areas largely covered by surficial deposits, the surface form is an important criterion for distinguishing between different genetic kinds of surface debris whose reflectance and, hence, image density, are indistinguishable. For these reasons, it is important to conduct part of the test using the straight video display rather than quantized or digitized video, in order to discern the surface form. After inspection of the straight video display, proper selection of position and widths of quantizing levels can be used effectively to enhance the appearance of the surface form or texture.

With multiband images--both 9-lens and color-separation images--the blue or green and the reflective infrared (frames 2 or 3, and 9) generally proved to be the most useful combination. This confirms results of the redundancy tests.

An important advantage of the electronic image enhancement system is that the results of a wide variety and combination of enhancement experiments can be displayed and studied in "real time"--that is, the output is an immediate response to the input. Displays can be evaluated and adjusted promptly to achieve optimum enhancement. Other enhancement systems, most of which can perform only one or a limited number of enhancement procedures, necessitate a time lapse before the enhanced product can be viewed.

This system has already proved (unpublished data by Philco-Ford Corporation) to be effective in showing different depths of water bodies, and has promise for use in study of such things as sedimentation and water pollution.

All of the present studies were based on images obtained from low-altitude aircraft. Studies of high-altitude and spacecraft images are warranted on the basis of results from low altitude. For example, enhancement of different soil color types seems quite feasible.

Although there is no direct evidence from the described experiments, it seems highly likely that this enhancement system can effectively map out subtle differences in reflective infrared photographs to show location and extent of diseased or poisoned vegetation, whether the poisoning is due to geochemical anomalies, changes in water table, or some other factors. In the present studies it was possible to delineate water-logged areas because of their effect on the vegetation. Also, deciduous forests were clearly distinguished in most places from evergreen forests.

A display or "map" such as that of figure 6B, which shows all areas of rock exposure as a unit, would be invaluable in places such as northern Maine and parts of Canada where a geologist might spend several days wandering around in the muskeg looking for an outcrop.

Any form of image enhancement has some drawbacks. In the deliberate distortion of image color and tone values, many tone values which identify familiar objects also become distorted--sometimes enhanced, sometimes suppressed--thus changing their interpretative significance.

With the possible exceptions of such operations as edge enhancement, nearly all methods of terrain study by means of enhancement of images require that the interpreter already have considerable knowledge about the geology or terrain shown in the image. He must know what kind of material he wants to enhance and where some of that material lies in the image. This need for prior knowledge holds true especially for electronic image enhancement systems because of the literally infinite number of settings possible.

Success of enhancement of image data is directly related to the interpreter's understanding regarding the problems and goals, and his knowledge of enhancement processes. For example, investigators interested in ocean depths have vastly different requirements and approaches than do those interested in crop differences, and they in turn differ markedly from those of us interested in geologic data.

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