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ABSTRACT

The U.S. Geological Survey is experimenting with the lithographic reproduction of color image maps from black-and-white film. Two high-altitude photographs are simultaneously exposed in two vertically oriented mapping cameras--one containing black-and-white panchromatic film filtered to record the visible spectrum and the other containing black-and-white infrared film filtered to record the near-infrared spectrum. Negatives of the two images are rectified, scaled, and processed to an optimum density range. Halftones are made by screening the negatives for various combinations of yellow, magenta, cyan, and black, depending on the color rendition desired. The 1:24,000-scale color image map produced has pleasing colors and the good resolution of an image map made from black-and-white panchromatic film.

INTRODUCTION

The U.S. Geological Survey publishes a series of black-and-white photoimage maps called orthophotoquads. An orthophotoquad is a rectified image in a standard quadrangle format, with little or no cartographic enhancement. Orthophotoquads are produced quickly and economically, and serve either as interim coverage of unmapped areas or as updated supplements to existing topographic maps.

When color tints and cartographic symbols are applied to an orthophotoquad, it becomes an orthophotomap and replaces the standard line map as published coverage. Orthophotomaps are time-consuming and expensive to produce, yet offer effective portrayals of areas such as swamps, marshlands, and deserts where contours alone cannot adequately depict the physiography.

Unfortunately, color orthophotoquads and color image maps are not being made in the USGS from conventional color or color-infrared film because color film has several drawbacks that have not been resolved: (1) Color photographs taken from flight heights required for quadrangle-centered frames (11,000 m or above) generally exhibit poor contrast due to atmospheric scattering of the shorter wavelengths; (2) although color-infrared film provides better differentiation at higher altitudes due to its haze-penetrating characteristics, the response in the visible part of the spectrum is still affected by atmospheric scattering; and (3) the processing of color images from film to the pressplate stage would necessitate a major investment in equipment and expertise. For example, rectifiers and cameras would have to be equipped with color-corrected lenses, and color-film-processing equipment and personnel would have to be acquired. However, in producing color image maps from black-and-white film, atmospheric scattering is no great problem, and virtually no change is needed in equipment already in use for producing black-and-white image maps.

The technique of combining two or more bands of black-and-white film to form color composites is not new. For many years, spectrally filtered images from multispectral camera arrays have been recombined and displayed in color through additive projection techniques, and color prints have been made from these combinations. Until recently, color composites of multispectral imagery have been used primarily as research tools for the interpretation of earth resources. They are now being recognized for their value as map bases.

The idea for producing color image maps by combining and assigning colors to the visible and infrared spectral bands of black-and-white aerial film came about as a result of the Survey's success in using a similar technique to produce 1:500,000-scale satellite image maps from two or more bands of imagery recorded by the Landsat multispectral scanner (MSS)[1]. Experiments indicated that MSS bands 5 and 7 were sufficient to portray the major mapping themes of vegetation, water, and culture. Therefore, it was reasoned that if two simultaneously exposed black-and-white aerial films could be filtered to have spectral responses similar to MSS bands 5 and 7, it should be possible to rectify, register, and print a 1:24,000-scale color image map in a rendition similar to that of color-infrared film.

LIVINGSTON, TEXAS, EXPERIMENTAL COLOR COMPOSITE

The first experimental color composite was produced from imagery of the Livingston, Tex., area, taken over a portion of the NASA Houston Test Site No. 175. The test site was chosen primarily for its accessibility to Ellington Air Force Base, and because it would provide both low- and high-relief imagery for experiments in both simple and differential rectification. NASA took the photographs on November 13, 1974, at 12,200 m (40,000 ft) from a WB-57 plane equipped with two Zeiss RMK A 15/23 mapping cameras.

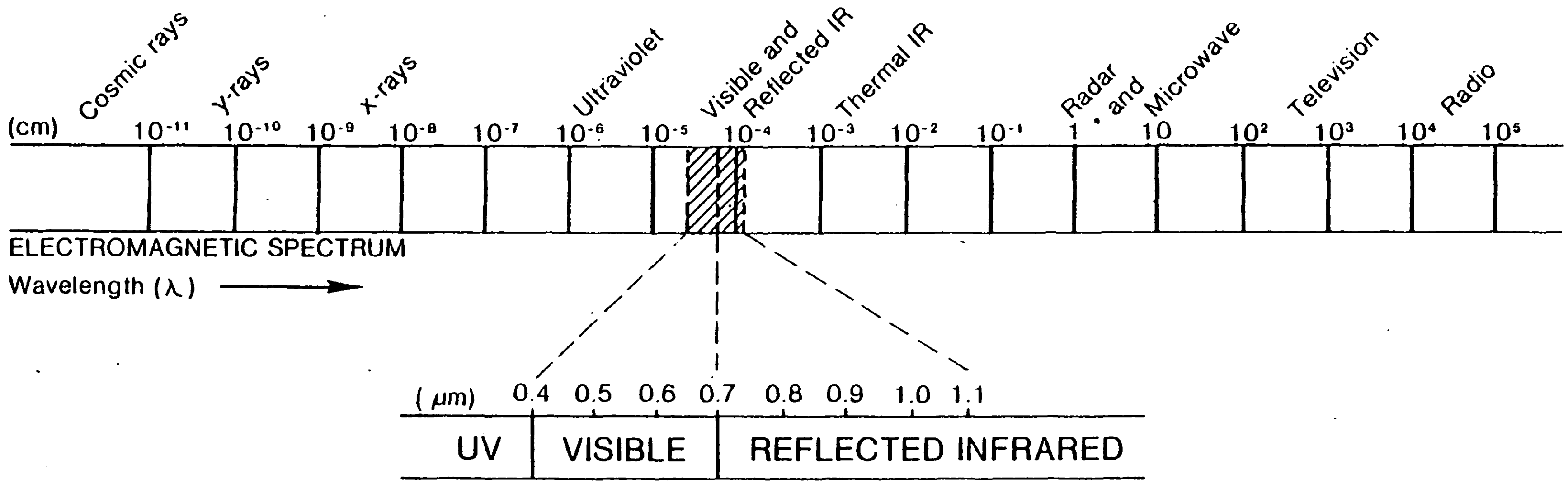
One camera contained Kodak 2402 film with a Wratten 25 filter for recording the red spectral band 0.6 - 0.7 μm. The other camera contained Kodak 2424 film with a Wratten 89B filter for recording the near-infrared band 0.7 - 0.9 μm which actually falls between MSS bands 6 and 7. The spectral sensitivity of infrared aerial film is limited to 0.9 μm, whereas MSS band 7 extends to 1.1 μm (fig. 1). Antivignetting filters were used but were insufficient to prevent the outer portion of the imagery from being too dark.

Although a north-south flightline coincident with the centerlines of published 1:24,000-scale maps was preferred, high-altitude winds caused the line to be flown east-west instead of north-south. Unfortunately, the substitute flightline corresponded to the border between three Texas quadrangle maps--Blanchard (1:24,000-scale), Camilla (1:24,000), and Livingston (1:62,500).

The Livingston composite was not published as an orthophotoquad because the exposure station used for this experiment did not completely cover any of the three standard quadrangles. This problem, coupled with the vignetting of the imagery, caused the Livingston composite to evolve only to the color-proof stage.

Simple Rectification

To prepare a single control base for rectification, eleven evenly spaced control points were circled on stable-base film copies of culture and road-fill plates of the Blanchard, Camilla, and Livingston quadrangles. The coordinates for each point were measured on a Bendix Datagrid Digitizer,



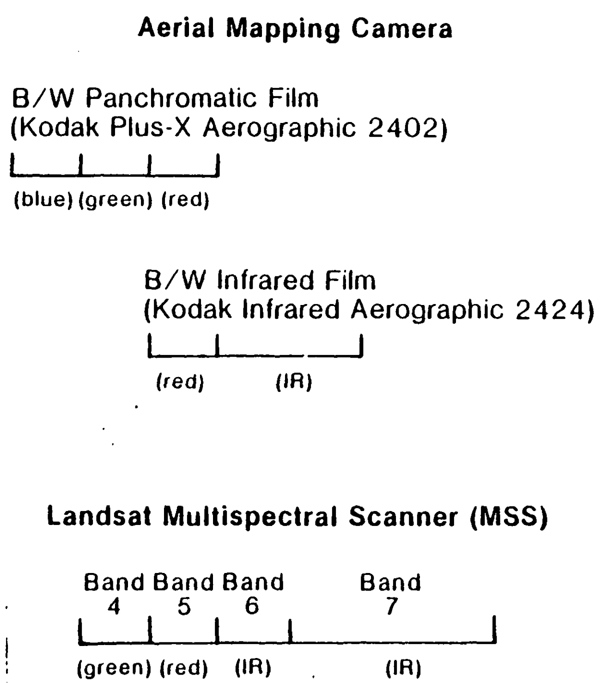


Figure 1.

Portion of electromagnetic spectrum enlarged to show spectral relationships between black-and-white aerial films used to make color orthophotoquads and MSS bands 4, 5, 6 and 7 used to produce Landsat color composites.

converted to State plane coordinates, and plotted at 1:24,000 scale on a Mylar base sheet. Film positives were made from both the panchromatic and infrared negatives, and using a Wild E-4 rectifier, they were independently rectified to fit the control base. Independent rectification was used because the two mapping cameras were not boresighted and had slight differences in degree and direction of tilt. Rectified negatives were processed to have a density range of 0.40 $\pm$ 0.10 to 1.40 $\pm$ 0.20.

Screening the Negatives

Three halftone positives were made from the two rectified negatives, two from the panchromatic negative for printing yellow and magenta, and one from the infrared negative for printing cyan (fig. 2). The negatives were screened in this manner to simulate the dye layers in color-infrared film and thereby achieve a simulated color-infrared response in the final composite. In color-infrared film such as Kodak 2443, cyan dye is used in the infrared-sensitive layer (0.7 - 0.9 μm), yellow dye in the green-sensitive layer (0.5 - 0.6 μm), and magenta dye in the red-sensitive layer (0.6 - 0.7 μm)[2].

Simulated Color-Infrared Cromalin Proof

Color proofs of Livingston were made using the DuPont positive Cromalin proofing system[3]. The advantage of this system is that its transparent subtractive toners can be matched in hue and density to press inks that are used for lithographic reproduction. The USGS has standardized a special set of four toners and matching press inks for image maps: yellow, magenta, cyan, and black.

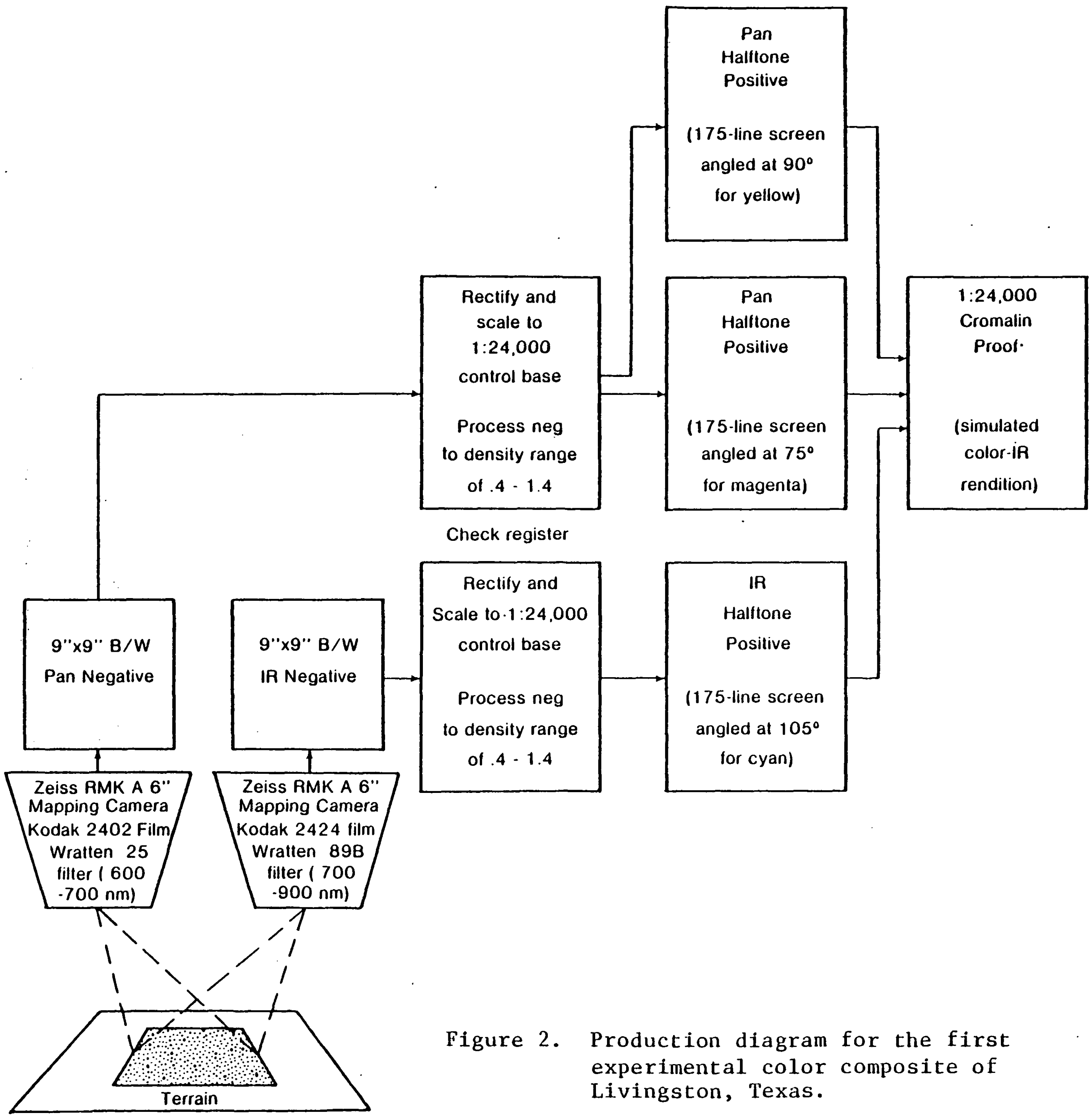


Figure 2. Production diagram for the first experimental color composite of Livingston, Texas.

In the final Livingston composite, vegetation appears in shades of red, turbid or shallow water appears in shades of pale to medium cyan, and deep, clear water appears almost black. Culture and uncultivated fields are depicted in shades of pale cyan, and cleared areas are white.

Image Register

A register check of the Livingston Cromalin proof indicated that the maximum amount of displacement between images was 0.38 mm at 1:24,000. scale or 9.12 m on the ground. To rule out the Cromalin process as a source of misregister, the same check was made on the three halftone positives and on the two rectified negatives, with the same results. The following were investigated as possible causes for misregister between the panchromatic and infrared images:

- Appreciably different lens distortion patterns between the two cameras;
- Improperly oriented filters, or filters with wedge angles greater than 10 seconds of arc;
- Cameras not boresighted;
- Shutters not synchronized;
- Inaccurate stud-registering of the two rectified negatives; and
- Film distortions.

Camera calibration data indicated that the differences in lens distortion patterns were negligible, and the filter wedge angles were less than 5 seconds of arc. The finished image register should not have been seriously affected by the cameras not being boresighted or the shutters not being synchronized. Slight differences in degree and direction of tilt between the two images should have been removed sufficiently through rectification.

The more likely causes of misregister seemed to be inaccuracies in stud-registering the two rectified continuous-tone negatives and the differences in the pattern of shrinkage between the two types of film. Corresponding terrain features did not image exactly the same on the two different films, making precise register of the two sets of imagery somewhat difficult. In analyzing the possibility of misregistration problems, it was reasoned that if a slight shift between the two negatives was introduced during stud-registering, the same constant shift would have been evident on the halftone positives and on the final composite. Measurements showed that the direction of image displacement between the orthonegatives of the two types of film were the same but that the magnitudes of displacement varied, indicating different film shrinkage patterns.

Differential Rectification on the Gestalt Photomapper II

In spite of the discrepancies between the panchromatic and infrared images, the color compositing technique was considered successful using simple rectification. The next step was to differentially rectify the same imagery on an orthophotoprinter and make another composite to check discrepancies and evaluate the visual effect of the scanning pattern. The images of both the panchromatic and infrared films were rectified on the Gestalt Photomapper II (GPM 2) to produce orthonegatives at 1:80,000 scale. Since two stereo-models covered the area, the two orthonegatives produced from each type of film were enlarged to 1:24,000 scale and mosaicked. A color composite was made from the mosaics. There was concern that enlarging and combining the two images would cause the hexagonal scanning patterns of the GPM 2 to become more pronounced, but the patterns were virtually undetectable.

Image Register

It was anticipated that differential rectification of the Livingston imagery would lead to an overall improvement in image register since the area had 100 m of terrain relief. Instead, the mismatch between scanned panchromatic and infrared orthonegatives was slightly greater than that found between the orthonegatives produced by simple rectification on the Wild E-4. For both the orthonegatives and final composite the maximum discrepancy between the imagery was 0.76 mm at 1:24,000 scale or 18.3 m on the ground. Possible factors contributing to this misregister are:

1. Correlation errors. These are reflected in the RMS errors in planimetry and height, automatically printed out on each orthonegative, indicating how each model fits the control:

PANCHROMATIC RMS ERRORS		INFRARED RMS ERRORS	
LEFT MODEL	RIGHT MODEL	LEFT MODEL	RIGHT MODEL
x = 131 μm	x = 81 μm	x = 139 μm	x = 59 μm
y = 71 μm	y = 33 μm	y = 83 μm	y = 28 μm
z = 52 μm	z = 30 μm	z = 17 μm	z = 6 μm

These are high RMS errors. The usual error in x, y, or z falls within 10 to 20 μm for 1:80,000-scale models with good input control, and an RMSE of 80 μm or more is considered excessive. Some of the large residuals have been attributed to errors in the identification of ground control.

2. Inaccurate transfer of control from panchromatic to infrared film positives. Control points were easy to locate on the panchromatic film but more difficult to transfer accurately onto the infrared film because of that film's low resolution.

3. Scale differences. To bring all four of the Livingston GPM 2 orthonegatives to 1:24,000 scale prior to mosaicking, an enlargement ratio of 3.328 was established on the Wild E-4 rectifier by fitting one of the panchromatic orthonegatives to two pass points plotted on a 1:24,000-scale base sheet.

This enlargement ratio of 3.328 was then used to enlarge the remaining three orthonegatives. However, a unique enlargement ratio should have been determined for each orthonegative from the GPM 2 because measurements showed that scales of the four orthonegatives involved differed slightly.

Scales determined from distances computed from Kern MK2 monocomparator measurements were:

PANCHROMATIC ORTHONEGATIVES		INFRARED ORTHONEGATIVES	
East half	West half	East half	West half
1:79,915.5	1:80,025.9	1:80,062.6	1:79,929.8

CANADA/UNITED STATES BORDER COLOR IMAGE MAPS

In September 1975 the U.S. Customs Service asked the U.S. Geological Survey to help them analyze their border mapping requirements. After evaluating several map products, including the experimental color composite of Livingston, Tex., the Customs officials felt that 1:24,000-scale color image-base composites, with UTM grids and planimetric overprints or overlays, might be useful border maps. The USGS was asked to prepare color image maps for a 200-mile strip of the international border from St. Regis, N.Y., to the Maine-New Hampshire line where heavy border traffic was expected during the summer Olympic Games in Montreal.

Aerial Photography

Aerial photographs were taken east to west along the border on Oct. 28, 1975, by the Canada Centre for Remote Sensing, in a Falcon jet equipped with two synchronized Wild RC 10 15-cm cameras and from a flight height of 10,600 m (35,000 ft). One camera contained Kodak 2402 film with a Wild 525 nm (minus-blue) filter for recording spectral band 0.5 - 0.7 μm (green and red). In the Livingston experiment, only the red band (0.6 - 0.7 μm) had been recorded on the panchromatic film because a Wratten 25 filter was used. The second Wild RC 10 camera used by the Canadians contained Kodak 2424 film with a Wild 705 nm filter for recording spectral band 0.7 - 0.9 μm (near-infrared).

Cromalin proofs of the 1:24,000-scale image maps were prepared in color-infrared renditions for evaluation by Customs officials. The maps were formatted to center on the Canada/U.S. border and match the 7.5-minute longitude limits of the related U.S. topographic maps for which they were named. They were designated "image maps" rather than orthophotoquads because their north and south boundaries do not coincide with the 7.5-minute latitudes of a standard quandrangle.

Experiment with Natural Color

Customs officials were pleased with the Cromalin proofs but had reservations about the simulated color-infrared portrayal of the imagery. They felt that a more natural color portrayal would be more acceptable to their field officers, and therefore asked the USGS to experiment with such a composite for evaluation.

Most of the Canada/U.S. border photographs required differential rectification for making orthophotos because of the amount of relief, so in addition to experimenting with natural color, it was decided to determine whether or not acceptable color orthophotos could be prepared and composites made from imagery rectified on the GZ-1 from profile data obtained on the USGS Digital Profile Recording and Output System (DPROS). The panchromatic and infrared negatives of Highgate Center, Vt. (later renamed Highgate Springs Port of Entry, Vt.-Quebec), were selected for further experiments with natural color and differential rectification on the GZ-1. A packet was made consisting of four renditions (I-IV) of the Highgate Springs Port Entry Color Image Map for evaluation by Customs officials: Rendition I was a black-and-white rendition made from the panchromatic image; Rendition II was a simulated color-infrared rendition (similar to the Livingston, Texas composite); Rendition III was portrayed in a simulated natural color rendition which involved density-slicing techniques; and Rendition IV was an alternate simulated natural color rendition made from images differentially rectified on the GZ-1.

In Rendition IV the panchromatic image was printed in yellow, cyan, and black, and the infrared image was printed in yellow and magenta (fig. 3). The addition of cyan gave vibrancy to the green tones in the composite and enhanced the distinction between cultivated and uncultivated fields. Customs Service preferred Rendition IV over all others so the series of 24 Canada/U.S. Border Color Image Maps was eventually printed in this rendition.

Differential Rectification

The Highgate Springs negatives used to produce Rendition IV were differentially rectified on the Digital Profile Recording and Output System (DPROS), which permits the manual production of digital profile data and subsequent exposure of orthonegatives. A stereoplotter is used to produce digital terrain profile data on magnetic tape. Quadrangle-centered photos are then scanned off-line on a high-resolution Zeiss GZ-1 Orthoprojector controlled by the magnetic tape data to produce orthonegatives. The standard procedure for obtaining orthonegatives from the DPROS combination would have been to use the panchromatic digital profile data to produce the panchromatic orthonegative and the infrared digital profile data to produce the infrared orthonegative. However, to avoid the possibility of misregister caused by variations in profiles, a new procedure was developed in which only the panchromatic

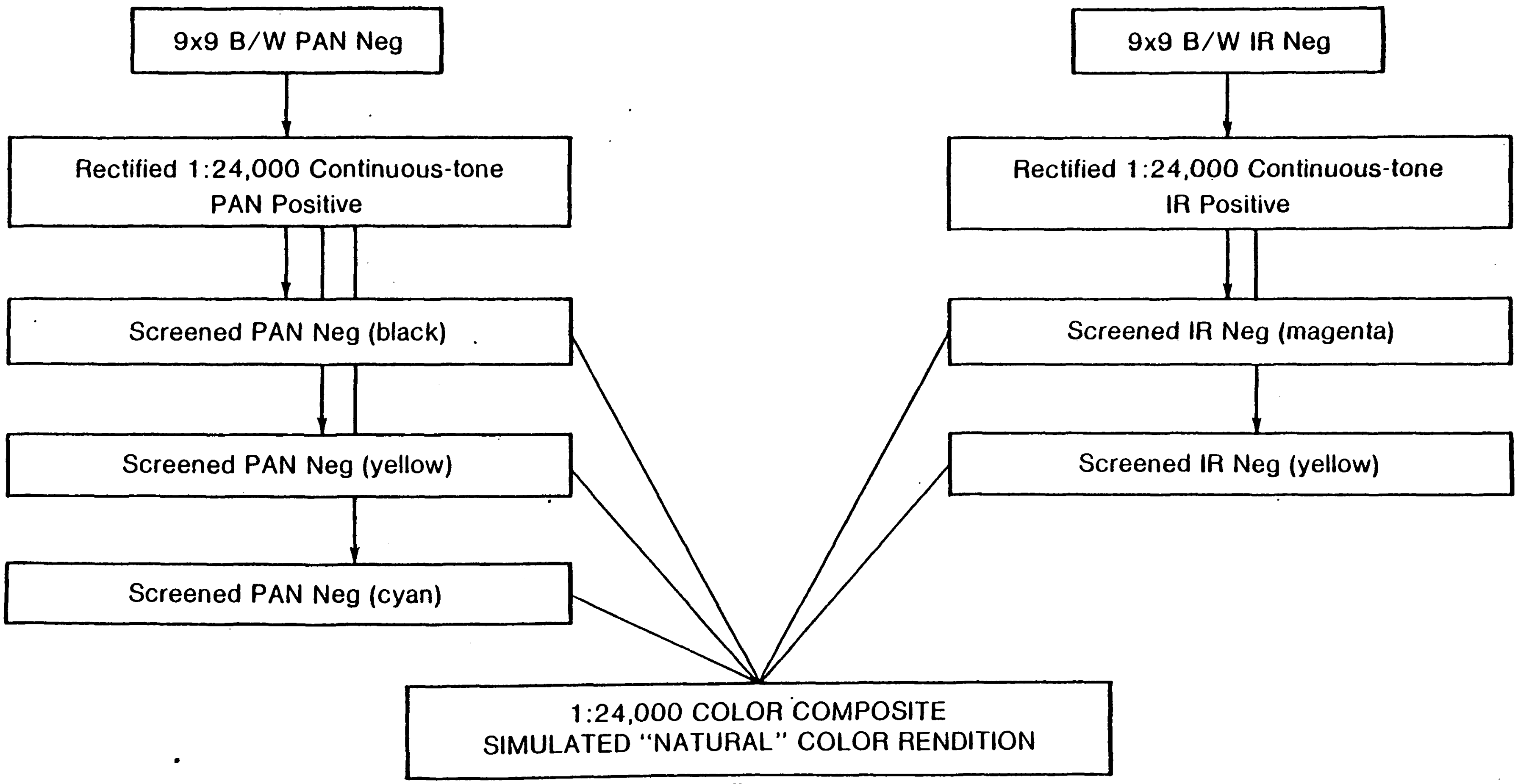


Figure 3. Production diagram for the simulated natural color rendition (Rendition IV) of the Highgate Springs Port of Entry, Vermont-Quebec, Color Image Map.

double model was scanned on the DPROS and the digital profile data were then used to produce both the panchromatic and infrared orthonegatives on the GZ-1 .

For differential rectification of twin-camera photography the DPROS has three advantages over the GPM 2:

(1) Excellent register between panchromatic and infrared orthonegatives is assured because both are produced from the same set of digital profile data; (2) orthonegatives are produced at 1:24,000 scale, rather than at model scale, eliminating the step of enlarging the orthonegatives; and (3) both models of the quad-centered photograph are printed out on the same orthonegative, eliminating the need for mosaicking.

SUMMARY

The USGS has lithographed 1:24,000-scale color orthophotos by combining and assigning colors to two types of black-and-white aerial film. Panchromatic and infrared images were simultaneously recorded in two mapping cameras at altitudes at or above 10,600 m. The two corresponding images were rectified, registered, screened and printed in various combinations of yellow, magenta, cyan, and black. Color composites produced from black-and-white film exhibit sharper tonal contrast and better resolution than equivalent high-altitude color or color-infrared photographs. Twin-camera imagery of Livingston, Tex., was used to produce the first experimental 1:24,000-scale simulated color-infrared composite. The first 1:24,000-scale color composites to be gridded, provided with a map collar, and lithographically reproduced by the USGS were the experimental Highgate

Springs Port of Entry, Vt.-Quebec, Color Image Maps. The final Canada/U.S. border series includes 24 1:25,000-scale maps printed in the simulated natural color Rendition IV.

Good register between panchromatic and infrared images is essential in the preparation of color image maps, but is not easy to achieve. Experiments have shown that excellent register can be achieved if the images are rectified on the DPROS because both orthonegatives can be produced from the same digital profile data. This cannot be achieved on the GPM 2 due to differences in the automatic correlation process between the two types of film.

Color image maps or color orthophotoquads make excellent companion maps to corresponding black-and-white orthophotoquads and line maps. If twin-camera imagery could eventually be incorporated into the USGS's black-and-white panchromatic orthophotomapping program, for special applications three additional map products could be made available on user request: (1) A black-and-white orthophotoquad prepared from the infrared image; (2) a simulated natural color rendition of the combined panchromatic and infrared images; and (3) a simulated color-infrared rendition of the combined images.

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